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USE OF WATER IN IRRIGATION

Orange orchard and residence of Mr. J. H. Williams, Porterville, Cal.

(*Frontispiece.*)

USE OF WATER
IN
IRRIGATION

BY

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To

THE MEMORY OF

MY MOTHER

PREFACE

It is well to recognize at the outset that irrigation is a many-sided subject. The heavy drafts which it makes on scanty water supplies and the close relationship which it bears to other uses of water call for wise legislation and efficient control on the part of state governments in the granting and protection of water rights and the equitable distribution of water supplies. These comprise the legal and administrative features of irrigation. Again, enormous quantities of water have to be annually stored in the mountains, pumped from wells, diverted from torrential streams, conveyed around hills and across valleys and finally delivered to farmers. The accomplishment of so great a task calls for high ability and broad experience on the part of engineers in designing and constructing the needed works and these constitute the engineering side of irrigation. Then there is the agricultural side of irrigation which transcends all others in importance, in that it deals with the production of profitable crops. All other phases of irrigation are but means to an end. The one great purpose is to transform desert places into gardens and orchards where the highest type of American citizens may establish homes. Lastly, running all through the subject like threads in a fabric, are to be found such features as proper organization, cooperation, good management and profitable returns. These may be grouped under the economic side of irrigation.

No work on American Irrigation would be complete that did not embrace all of these salient features. On the other hand, the time required to prepare so much material would cause the first part to be out of date before the last was written. So it has been deemed best to consider but one phase of the subject at a time and to publish the material which properly belongs to that phase in a separate volume.

The volume here presented deals with the agricultural side of irrigation under the somewhat broad title, Use of Water in Irrigation. It aims to benefit at least three classes of readers.

The first comprises the new settlers and those who are looking to the West as a suitable place to establish homes. The second includes the irrigation farmers and those who are interested in irrigated agriculture; and the third class comprises students in agricultural high schools and in the agricultural and engineeiing classes of colleges and universities. The subject matter is confined almost exclusively to the irrigated farm and to the problems which confront the irrigator. In this respect it is an Irrigator's Handbook. The legal, economic and engineering phases of the subject are touched upon but only insofar as they affect the welfare of the farmer. Considerable space has been given to methods of preparing land and applying water for the reason that the manner in which these are done determines to a large degree the profits derived by the farmers and the success of canal companies. Considering the rich soil and favorable climate of arid America, the average yields under irrigation are small. This is mainly due to the adoption and use of faulty methods in watering fields and maintaining moisture conditions in the soil. It is hoped that out of the many methods herein described the farmer may adopt those best suited to the conditions on his farm and thus pave the way for profitable returns.

The manner in which water is used in irrigation as described in these pages is nation-wide. The same care and attention which were paid to the irrigation of cotton and sugar cane in the Southwest, to rice in the Gulf States and to truck and fruit crops along the Atlantic seaboard were given to the irrigation of forage and cereal crops in the Mountain States and to vineyards and orchards along the Pacific. To cover so wide a field is much beyond the range of experience of any one man and in this connection the author gratefully acknowledges the assistance rendered by members of the Division of Irrigation Investigations of the Office of Experiment Stations, U. S. Department of Agriculture. For more than a dozen years this faithful band of technically and scientifically trained men have worked with and for the irrigators in their efforts to increase the productivity of land, establish homes and create more prosperous farming communities through the agency of water wisely used. Whatever of merit this publication may

possess is due in the main to the writings and views of these co-workers in the development of irrigation in this country. It records the experiences gained in the field and laboratory rather than what may be compiled in a library.

The author likewise desires to acknowledge his indebtedness to the HONORABLE DAVID F. HOUSTON, Secretary of Agriculture, for permission to publish this Handbook and to DR. A. C. TRUE, Director of the Office of Experiment Stations, for permission to make use of the publications and illustrations of the Office.

S. F.

WASHINGTON, D. C.,
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CHAPTER I

INTRODUCTION

Those who have watched the rise and progress of Western commonwealths must have observed how large a part of their total revenue is derived from irrigated products. Irrigated agriculture lies at the foundation of much of the material prosperity of the West. Through the agency of water wisely used, deserts are converted into productive fields and orchards, and flocks and herds and prosperous communities take the place of wild animals and an uncivilized race. It also furnishes food and clothing for the dwellers in cities, raw material for the manufacturer and traffic for the transportation company. If it were possible to remove from the arid region the comparatively small area which has been rendered highly productive by means of irrigation, it would go far to undo the labor of half a century in building up the western half of the Union.

Extent of Irrigation in the United States.—The extent of irrigation in the United States is shown in the following table compiled from Census data. The first column of figures gives the acreage actually irrigated in 1909, in each of the seventeen western states, the Gulf states and throughout the humid region, the second column the acreage which the enterprises were capable of irrigating in 1910 and the third column the acreage included in enterprises either completed or under way July 1, 1910. In the last column of the table is given the estimated value of irrigated crops in each of the seventeen western states and also in the rice belt of the Gulf states.

TABLE No. 1

State	Acreage irrigated in 1909	Acreage enterprises were capable of irrigating in 1910	Acreage included in enterprises	Estimated value of irrigated crops in 1910[1]
Arizona	320,051	387,655	944,090	$5,765,030
California	2,664,104	3,619,378	5,490,360	70,849,320
Colorado	2,792,032	3,990,166	5,917,457	56,312,392
Idaho	1,430,848	2,388,959	3,549,573	27,684,194
Kansas	37,479	139,995	161,300	1,781,617
Montana	1,679,084	2,205,155	3,515,602	19,040,620
Nebraska	255,950	429,225	680,133	3,335,328
Nevada	701,833	840,962	1,232,142	9,910,080
New Mexico	461,718	644,970	1,102,297	7,997,628
North Dakota	10,248	21,917	38,173	120,483
Oklahoma	4,388	6,397	8,528	88,851
Oregon	686,129	830,526	2,527,208	9,104,225
South Dakota	63,248	128,481	201,625	1,031,388
Texas	164,283	340,641	753,699	5,416,346
Utah	999,410	1,250,246	1,947,625	18,317,086
Washington	334,378	470,514	817,032	11,251,647
Wyoming	1,133,302	1,639,510	2,224,298	10,750,592
Gulf States	694,800	950,706	950,706	15,000,000
Humid Region	30,000	30,000	30,000	3,000,000
Total	14,463,285	20,315,403	32,091,848	276,756,827

Agencies in Irrigation Development.—Out of a total of over 14,000,000 acres the individual irrigator who has either built a ditch himself or formed a partnership with one or more neighbors has reclaimed and irrigated 6,624,614 acres. Next in order come the cooperative companies which are really larger groups of farmers acting together in building the necessary works. Next come the commercial enterprises of one sort or another which have launched into the business of furnishing a water right and selling it to the irrigator. Public irrigation corporations known as irrigation districts, the U. S. Reclamation Service, companies operating under the Carey Act, and the U. S. Indian Service, comprise the remainder of these agencies. The extent of land which was reclaimed by each of these agencies at the close of 1909 is given in the following table.[2]

[1] Compiled by P. A. Ewing, formerly connected with the Irrigation Census.

[2] Irrigation in the United States by R. P. Teele, 13th Census.

TABLE NO. 2

Agency	Acres
Individual and Partnership Enterprises	6,624,614
Cooperative Enterprises	4,643,539
Commercial Enterprises	1,809,379
Irrigation Districts	528,642
U. S. Reclamation Service	395,646
Carey Act Enterprises	288,553
U. S. Indian Service	172,912
	14,463,285

Cost of Irrigation in the United States.—The total cost of irrigation falls naturally into two divisions. One of these represents the cost of the works necessary to provide a water supply and to convey it to within easy reach of each farm. The other represents the cost of preparing the land in such a way that it can be irrigated together with the cost of farm ditches and structures.

The cost of irrigation works for each western state up to July 1, 1910, as found by the Census is given in Table 3 and

TABLE NO. 3

State	Average cost per acre of preparing land	Cost of works to July 1, 1910	Estimated cost of preparing land irrigated in 1909	Total estimated cost
Arizona	$13.75	$17,677,966	$4,401,000	$22,078,966
California	19.25	72,580,030	51,284,000	123,864,030
Colorado	14.50	56,636,443	40,485,000	97,121,443
Idaho	11.60	40,977,688	16,598,000	57,575,688
Kansas	10.50	1,365,563	394,000	1,759,563
Montana	12.50	22,970,958	20,989,000	43,959,958
Nebraska	10.50	7,798,310	2,687,000	10,485,310
Nevada	10.00	6,721,924	7,018,000	13,739,924
New Mexico	13.50	9,154,897	6,233,000	15,387,897
North Dakota	11.00	836,482	113,000	949,482
Oklahoma	10.50	47,200	46,000	93,200
Oregon	15.00	12,760,214	10,292,000	23,052,214
South Dakota	12.00	3,043,140	759,000	3,802,140
Texas	19.00	7,346,708	3,121,000	10,467,708
Utah	15.00	14,028,717	14,990,000	29,018,717
Washington	16.00	16,219,149	5,350,000	21,569,149
Wyoming	9.00	17,700,980	10,200,000	27,900,980
Totals	....	$307,866,369	$194,960,000	$502,826,369

amounts in the aggregate to $307,866,369. The estimated final cost of such works when all the enterprises which were either completed or under way in 1910 are included, is given in Table 4 and aggregates $424,281,186.

The various items of cost comprised in the second division were estimated by the state agents of Irrigation Investigations, Office of Experiment Stations, U. S. Department of Agriculture, located in the states where irrigation is practised. These were based on the amount of money expended by farmers in clearing the land of desert growths, plowing, leveling and grading it, building the necessary supply and farm ditches with their accompanying structures and in general preparing the land for irrigation and profitable crops. Table No. 3 gives the average

TABLE NO. 4

State	Average cost per acre of preparing land	Estimated final cost of works	Estimated final cost of preparing land in projects	Total estimated final cost
Arizona	$13.75	$24,828,868	$12,981,000	$37,809,868
California	19.25	84,392,344	105,689,000	190,081,344
Colorado	14.50	76,443,239	85,803,000	162,246,239
Idaho	11.60	58,451,106	41,175,000	99,626,106
Kansas	10.50	1,365,563	1,694,000	3,059,563
Montana	12.50	32,382,077	43,945,000	76,327,077
Nebraska	10.50	9,485,231	7,141,000	16,626,231
Nevada	10.00	12,188,756	12,321,000	24,509,756
New Mexico	13.50	11,640,091	14,881,000	26,521,091
North Dakota	11.00	836,482	420,000	1,256,482
Oklahoma	10.50	47,200	90,000	137,200
Oregon	15.00	39,216,619	37,908,000	77,124,619
South Dakota	12.00	3,800,556	2,420,000	6,220,556
Texas	19.00	8,613,533	14,320,000	22,933,533
Utah	15.00	17,840,775	29,214,000	47,054,775
Washington	16.00	22,322,856	13,072,000	35,394,856
Wyoming	9.00	20,425,890	20,019,000	40,444,890
Totals	....	$424,281,186	$443,093,000	$867,374,186

cost per acre of such preparation in each of the western states. The product of this unit cost and the acreage irrigated in 1909 is likewise given in the table for each western state and comprise in the aggregate the sum of $194,960,000.

In estimating the cost of preparing land for enterprises not

completed in 1909 the same unit costs were used. These when multiplied by the number of acres contained within completed and incompleted enterprises are given in Table No. 4 and comprise a total expenditure by the farmers under irrigation enterprises, inclusive of the amount expended for like purposes prior to 1910 of $443,093,000 or $18,811,814 more than the entire cost of the construction of irrigation works.

Many will be surprised to learn of the large expenditures necessary before the business of irrigation farming can be successfully carried on. These data show that water rights prior to 1910 cost on an average 62 per cent. of the total and that the final cost will be below 50 per cent. of the total, the balance being expended in the building of ditches and structures on the farm and in grading and smoothing the surfaces of fields to permit the proper application of irrigation waters. They likewise show the large expenditure necessary in each western state before the land included in projects and not irrigated in 1909 is made remunerative.

The people of this country have been greatly interested in the construction of works to reclaim desert lands. Land agents and others engaged in the settlement of these lands have fostered this interest by magnifying the importance of such works and at the same time ignoring the heavy expense which has to be incurred by the settler before such lands can be made productive. The erroneous impressions which have been formed in the minds of credulous people by land agents and press agents in giving out one-sided information by means of circulars, press notices and illustrated lectures, have been the indirect cause of great suffering and disappointment among the settlers of irrigation projects and of irreparable loss to capital invested in irrigation enterprises.

This volume will have served a useful purpose if it corrects some of these erroneous impressions. It is thought no one can peruse its pages without being impressed with the large amount of money which must be expended between the time water is ready to be delivered and the time when the farm is on a paying basis. The information which it contains has been prepared with the object of assisting the irrigator in the design and execution of that part of the work which he must perform. The

measure of his success will represent the measure of the success of the irrigation enterprise of which he forms a part since it is the labor of the irrigators skillfully directed which determines the value of such properties.

CHAPTER II

THE IRRIGATED FARM

1. Location and Selection of a Farm under Irrigation.—The prospective settler usually decides upon the kind of farming which he wishes to follow, basing his decision upon the experience and knowledge of various phases of the subject which he has acquired. Having arrived at this decision he should then seek for a suitable location.

The selection of a farm, to be operated under irrigation, should be made only after carefully investigating the climate, soil, drainage, crops to be raised, transportation facilities to local and distant markets, and the social and educational advantages of the various localities. Since health is paramount all malaria and fever infested districts should be shunned no matter how many advantages they possess in other respects. Except where health must be considered climatic conditions in general should only be given the same weight as the other factors involved. These conditions are different throughout the various sections of the country and will be found to vary for even a given locality. In the valleys and lowlands frost occurs later in the spring and earlier in the fall than upon the adjacent ridges and tablelands thus producing a slightly shorter growing season for the same locality. The decision regarding the kind of farming to be followed will usually determine the section of the country to be investigated.

Special consideration should be given to the character of the soil since all plants require certain nutrients to sustain life. These must be present in the soil in an available form before crops can be successfully grown. When the supply of plant food is not available or is deficient in some elements the defect can be remedied only by skillful treatment or the application of artificial fertilizers at the expense of labor and capital. Only those soils which contain plenty of plant food should be selected.

The surface and subsurface conditions of the soil should like-

wise be considered. A surface with knolls and hollows requires leveling for irrigation. Leveling involves the removal of earth from the knolls and the filling in of the hollows, thus the rougher the surface the more costly will be its preparation for irrigation. An ideal farm for irrigation should have an even surface which slopes uniformly in one or two directions. Land with a good surface slope has two advantages, it is easily irrigated and readily drained. Formerly drainage was given little consideration but the consequences resulting from continuous irrigation show that irrigated land must have proper drainage. Should the soil be underlaid with an impervious stratum excessive applications of water may raise the water table and damage crops. The continual evaporation would likewise precipitate the salts, which have been dissolved out of the soil, upon the surface and impregnate the surface with alkali. A porous subsoil would allow all excess water applied to the land to pass downward and thus prevent injurious results. On the other hand, too porous a soil may waste valuable water through deep percolation.

Both soil and climatic conditions should be studied for the purpose of determining what crops can best be grown under these conditions. The crops grown in a newly developed district are usually a poor guide since they are consumed at home or within the district. Under such conditions prices are usually high whereas if an extensive area be planted to these same crops the local price may fall so low that it will not be profitable to produce them.

It is thus apparent that the selection of profitable crops to be grown involves a study of transportation facilities and a proximity to outside markets. If crops have to be shipped long distances attention must be given to the selection of those which will sell for a relatively high price per pound or else the freight charges may consume all possible profits. Bulky crops which sell for a small unit price may be converted into finished products on the farm, by such means, for instance as the feeding of livestock for market. Profitable returns may be realized in this way yet every mile distant from the railroad and likewise from the open market increases the cost of production. Hence the farm should be located so that it is in reasonably close proximity to railway facilities and not too great a distance from good markets.

At first social and educational advantages are rather limited in a newly developed section. Provisions for schools, however, are usually made a part of the administrative policy of irrigation projects and they are established whenever the attendance is sufficient to warrant such institutions. In the West instances are common where schools were organized as soon as some four or five children of school age resided within the district. Schools are closely followed by social and religious activities which tend to the uplift and betterment of the community.

At the beginning the farm has but a slight intrinsic value but as improvements are made and as social and educational conditions become better, its value rises. Again, as the community becomes better settled small towns and villages may spring up which will tend to enhance its value still more. Even though proximity to a town and favorable social and educational facilities can not be had to the extent desired the settler has it in his power to make his farm highly productive and valuable by the adoption of good methods of farming skillfully carried out.

Farming under irrigation along the Atlantic seaboard is at present confined to valuable truck and fruit crops. These are usually grown in the warmer and earlier sandy, muck or peat soils which yield large returns under proper treatment. The essentials of such treatment are intensive culture, an abundance of fertilizers and proper moisture control.

Soil moisture and frosts are the most difficult to control and the chief causes of crop failures. However, an excess of moisture can be readily removed by tile drainage and any deficiency can as readily be supplied by irrigation. The dangers from frost can be greatly lessened by selecting the right location and by maturing the crops with the least delay. It is in this connection that irrigation plays an important part. By its means the seed bed can be prepared and the seed planted regardless of dry weather. A light irrigation at the right time also keeps the plants in a vigorous condition until maturity.

2. Lands Open to Settlement by Purchase or Entry.—Before acquiring western land the prospective settler should first consider the opportunities to which his circumstances make him eligible. If he has money or credit he may purchase an improved

farm in one of the older districts. The price of fertile and improved farms with a reliable water right varies between wide limits. Those which produce good yields of alfalfa, grain and root crops range in price from $50 to $200 per acre; deciduous orchards, vineyards and diversified farms near towns and cities are worth from $200 to $500, while citrus orchards can seldom be purchased for less than $1000 per acre.

The wealth in irrigated farms which now yield a yearly revenue of over $276,000,000 was created by men who were poor in worldly goods but rich in those physical and mental qualities which go to make up the best type of citizenship. If the prospective settler belongs to this class it would seem wise for him to select a tract of raw land and by the exercise of brain and brawn transform it into a highly productive and valuable farm.

To those who are equipped with more vigor and courage than cash capital there is still good arable raw land available in the West. Settlement under the desert land act is confined for the most part to localities where the settler secures a water right from some canal already built. The individual entryman is seldom able financially to put in his own system of irrigation. Sometimes this can be done by the union of several entrymen. Opportunities for settlement under the homestead law upon lands susceptible of irrigation are at present few and hard to find, but large areas acquired under this law in the past are now irrigated with water purchased from canal companies.

To those who are unfamiliar with local conditions the best openings for settlement are to be found on the vacant lands included in the many irrigation enterprises for which a water supply has been provided. The following figures taken from the Census of 1910 show the extent of such land awaiting reclamation and settlement in that year under the agencies named.

	Acres
Cooperative enterprises	4,186,658
Commercial enterprises	3,668,171
Carey Act enterprises	2,265,321
U. S. Reclamation Service	1,677,370
Irrigation districts	1,052,823
Total	12,850,343

The foregoing figures include the unirrigated portions of farms and a large area in the aggregate which for one reason or another may never be irrigated. Even when all such areas are deducted there remains a vast extent of land for which water has been provided but which is unreclaimed for lack of settlers.

Some information for the prospective settler is briefly summarized by F. C. Scobey, Irrigation Engineer of the Office of Experiment Stations in the following schedule. (Table No. 5.) For the exceptions to the statements made therein and for more detailed information the reader is referred to Circulars 6, 116, 253, 290 and the general reclamation circular of the U. S. Land Office, all of which publications may be had free on application.

3. Water Supply.—According to the 13th Census approximately 95 per cent. of the land irrigated in 1909 was irrigated from streams. The remainder consisted of 452,000 acres irrigated from wells, 196,000 acres from springs, 98,000 acres from stored-water reservoirs, and 70,500 acres from lakes. Most of the streams used for irrigation rise in the higher mountains and are fed mostly by melting snows. This results in a flood flow in the late spring and early summer when the snows are melting rapidly and rains are occurring in the lower altitudes, and a low flow during the remainder of the summer, when the only sources of supply are the melting of glaciers and the last of the higher snowbanks, and seepage from saturated lands. Consequently, nearly all the streams carry more water in the flood season than can be used, while in summer, when there is the greatest need for water, there is a serious shortage. A tabulation made by the Bureau of the Census of the flow in 1909 of twelve of the largest streams draining the Rocky Mountains and the east side of the Cascade Range shows the aggregate June discharge of these streams to have been nearly four times the aggregate August discharge. The flood discharge of individual streams is commonly five to ten times that of the low-water flow.

The low-water flow of most of the streams of the arid section is utilized by the present irrigation works, and the greater part of the future extension of irrigation will depend upon the storage of the winter and the flood flow of streams. On many streams, notably those of Colorado, storage has been practised

TABLE No. 5

Table of General Information Concerning Land Available to the Prospective Settler

	Fee simple	Desert entry	Homestead entry	Carey Act	Irr. Dist.	U. S. R. S.
Who are qualified?						
All citizens of U. S.	Yes	No	No	Yes	Yes	No
Men over 21 years	.....	Yes	Yes	......	......	Yes
Married women	.....	Yes	No	......	......	Yes
Widows or deserted wives	.....	Yes	Yes	......	......	Yes
Single women over 21 years	.....	Yes	Yes	......	......	Yes
Heads of families under 21 yrs.	.....	.....	Yes	......	......	.....
Acreage limit to one settler	None	320	160	160	None	10–160
Is land assignable before patent issues?	.....	Yes	No	Yes	......	Yes
Is residence on land required?	No	No	Yes	Yes	No	Yes
Is a dwelling required?	No	No	Yes	Yes	No	Yes
Is cultivation of land required?	No	Yes	Yes	Yes	No	Yes
Is water supply for irrigation required?	No	Yes	No	Yes	Yes	Yes
Is property liable for irrigation charges?	.....	.....	....	Yes	Yes	Yes
What time is allowed before final proof in years?	.....	4	7 or 5	3	......	20
What time must elapse before final proof unless commuted?	.....	.....	5 or 3	......	......	.....
Immediate money necessary per A.	Variable	25c.	Nominal	25c.	......	1st pay
What is eventual cost per acre aside from labor?	do	$3.25	do	$10–65	do	$30–110
May irrigation water be secured from:						
An individual or partnership system?	Yes	Yes	Yes	Yes	Yes	No
A commerical co. system?	Yes	Yes	Yes	Yes	Yes	No
A Carey Act company?	Yes	Yes	Yes	Yes	Yes	No
A cooperative company?	Yes	Yes	Yes	Yes	Yes	No
An irrigation district?	.....	Yes	Yes	Indirectly	Yes	No
U. S. Reclamation Service?	Yes	Yes	Yes	do	Yes	Yes

for a number of years. The Census reported that in 1909 there were 6800 reservoirs having an aggregate capacity of 12,581,000 acre-feet used for storing water for irrigation in the arid section.

While much storage is being provided for by Carey Act and other projects it is along this line that the U. S. Reclamation Service is doing its most important work. Its great storage dams on the Salt River in Arizona, on the Boise River in Idaho, on the North Platte in Wyoming and in many other streams of the West have greatly increased the available water supply of that region.

Next to the storage of the winter and flood flow of streams, the extension of irrigation will depend upon pumping from wells and the storage of storm waters in reservoirs. Large areas of arable land throughout the arid sections can not be irrigated economically from streams, but are underlain at comparatively shallow depths with good supplies of ground water. One of the most conspicuous facts in the irrigation development of the last few years has been the rapid increase in the area irrigated from wells. The improvements that have been and are being made in pumps and pumping machinery, gasoline and other engines, and the rapid increase in the cost of obtaining water supplies from streams, have been the chief causes of this rapid development. As yet California is the only state in which the use of underground waters has developed to such an extent that laws other than the common law of percolating water have been applied to its use.

There are also large areas of arable land, especially on the Great Plains, which can not be irrigated from streams but which are rolling enough to afford many opportunities for small reservoirs in which to store storm waters with which to water small acreages, in connection with larger acreages used for dry-farming and grazing.

4. Water Rights.—The right to use the water of streams, lakes, etc., for irrigation and other purposes is defined by the constitutions, statutes, and court decisions of the different states, and as a result water rights vary materially in the different sections. As Mr. F. G. Harden of the Department of Agriculture has well stated, the law of water rights in all the arid states is in a formative state and is being changed constantly by

new statutes and court interpretations with a view to better meeting the changing conditions and necessities of the different sections.

Three doctrines regarding the source and nature of water rights have existed in the arid sections of the United States, and there are in existence at present rights based upon each of these doctrines. In nearly all the states there is some water used for irrigation under the common-law doctrine of riparian rights. The rights to use such water were vested at the time of the enacting of existing water laws, as the doctrine of riparian water rights is not recognized at present in an unmodified form in any arid or semi-arid state. It does exist, however, in a modified form in California, Kansas, Oregon, and Washington. Under the common law riparian rights attach to all lands abutting on a stream, and the possessor of such lands is entitled to have the stream flow by his land undiminished in quantity and unimpaired in quality. Such rights can not be lost by disuse and can be separated from the land only by specific grant. Strictly applied, the doctrine precludes the use of water for irrigation and consequently has been abandoned or modified in all the arid states.

In Texas and the states created out of the territory acquired from Mexico there is some water used, the rights to which are based upon old Spanish or Mexican grants to individuals, companies or pueblos, the old rights being recognized by treaties and laws of the United States and the states. These rights vary widely, as under the civil law the water belonged to the crown and in making a grant any restrictions desired could be placed in the grant.

The lands irrigated under the two classes of rights mentioned, however, comprise only a small percentage of the lands under irrigation, the remainder being watered under rights based upon appropriation and use, a doctrine originating in the necessity and customs of the early miners and irrigators. Under this doctrine the water belongs to the public and the state merely regulates its use, the right to make use of the water being obtained by taking, or appropriating, the water, and putting it to a beneficial use. The right so gained continues as long as the use continues and is not in conflict with earlier appropriations from the same source.

Under existing legislation, there are two methods of acquiring water rights. Many of the early rights rest merely on appropriation and use without any formalities whatever. The only formalities required even at present in Arizona, California, Kansas, Montana, and Washington are that a notice be posted at the point of intended diversion, stating the amount of water claimed, the purpose for which it is claimed, the place of intended use, and the manner in which the water is to be diverted; and that a copy of this notice be filed within a certain time with some public official, usually the county clerk or recorder. Having complied with these formalities, the appropriator is required to begin construction of his ditch or other works within a specified time to prosecute the work diligently and uninterruptedly to completion, and to make beneficial use of the water. These formalities having been complied with, the right dates back to the time the notice was posted. No records of construction or use are required to be filed, and consequently the records of claims are of little value in determining the value of a water right. The determination of the value of such a right is made still more difficult by the fact that the records in all the counties through which the stream flows must be examined, since claims may be filed in any or all of the counties, and by the fact that rights may be acquired by diversion and use without complying with any formalities regarding posting and recording notices. Such rights, however, date only from the time the water is actually put to beneficial use and are antedated by all perfected rights for which notices were posted and filed before the water was actually put to use.

In all the other states, except Colorado, it is necessary to apply to the state for a permit to appropriate and use water. This system of requiring the permission of the state to appropriate and use water is correctly known as the Wyoming system. The laws of all the other states are modelled after that of Wyoming which was drafted by Dr. Elwood Mead then State Engineer of Wyoming. The data required in the applications vary somewhat in the different states, but in general the following are asked for: The name and address of the applicant; the source and intended use of the water; the nature of the ditch or other works; maps showing the location and extent of the ditch; the

location and area of the land to be irrigated; the dates when construction will begin and when the works will be completed and the water put to the intended use.

The procedure, upon receipt of the application by the state engineer or state board to which application must be made, also varies somewhat in the different states, but in general is as follows: The application is examined to ascertain whether it is in proper form and complies with the laws and regulations, and if so, it is recorded and it is the duty of the state engineer or state board to approve the application and issue the permit if there is unappropriated water in the source of supply provided the proposed use will not impair the value of existing rights or be detrimental to the public welfare. The permit issued by the state engineer or state board fixes the amount of water which may be appropriated, the time within which the works must be begun and completed and the waters put to a beneficial use. Upon submission of proof that the conditions of the permit have been complied with, a certificate is issued by the state showing what rights have been acquired. About 15 per cent. of the acreage irrigated in 1909 was irrigated under permits or certificates from the state, so small a percentage being due to the fact that the laws providing for this method of securing rights have been on the statute books for only a few years, the earliest, that of Wyoming, having been enacted in 1890, and the most recent, that of Texas, in 1913.

Although Colorado was the first state to adopt the state control of waters, it does not require that any application for a permit to appropriate water, or that proof of the construction of works and use of the water be filed with any state official. It does require, however, that within 60 days after construction for the purpose of appropriating water is begun, a statement, together with maps, must be filed with the state engineer, setting forth the place of diversion, the nature of the works, the date of commencement of construction, estimated cost of the project, etc., and that if the data so given are sufficient and satisfactory to the state engineer, a copy shall be filed with the recorder of the county in which the headgate is located. These records furnish no index to the existing rights to water from the same source of supply.

The adjudication of rights which are not defined when acquired is left to the courts in all the states but Wyoming, Nebraska, Nevada, and Texas, in which states it is left to administrative boards. The laws of most of the states provide that when an action regarding a water right is brought all parties having claims to water from the same source must be parties to the suit so that the rights may be adjudicated by one action.

The laws of practically all the states provide that water can be used only upon the land for which it is appropriated, consequently, when it is not being used upon such land it must be left in or turned back into the stream for use of other appropriators. The amount of water that can be beneficially used, is the limit in all the states of the amount that can be appropriated for a given tract of land. This is further limited in most of the states to an amount not exceeding 1 second-foot continuous flow for each 50, 70, or 80 acres. Non-use for a period of 3 to 5 years constitutes an abandonment of a right in most states if the right has been acquired by appropriation and use.

The purchaser of a tract of land with a water right should exercise as much, or more, care in determining the validity of his water right as he does in examining the title to his land. The few transfers that have been made of the lands and the complete record of such transfers and the liens against lands in the offices of the recorders or clerks of the counties in most of the western states make the examination of the title to land comparatively simple. Examinations regarding water rights, on the other hand, are very complicated, owing to the various methods by which rights may be acquired, the lack of records of existing rights, the grounds that may be set up to destroy a right or change its priority, the fact that all except the very earliest priorities on the stream are dependent upon the low-water flow, and the difficulty of securing proof of continuous use and compliance with laws regarding the appropriation of water.

According to the 13th Census, 35 per cent. of the land irrigated in 1909 was under rights that had been adjudicated, approximately 6 per cent. under certificates from the state, and 7 per cent. under permits from the state, thus making approximately two-fifths of the acreage under rights that were determined as to extent and about one-fourteenth under rights that

2

would be so determined as soon as the appropriations and use were completed. The other half of the acreage irrigated consisted of 2 per cent. under riparian rights, 34 per cent. under appropriation and use, and 16 per cent. under notices posted and filed, all of which rights are undefined and more or less indefinite as to extent, although many of them are perfectly valid. On the other hand, the fact that the right has been adjudicated or defined is not an absolute guarantee of the extent or value of the right, as the appropriator may be entitled to water only in times of flood, only when the flow is considerably above the low summer stage, or only at certain periods of the year; the right may have been lost or lessened since the adjudication by abandonment, and in some cases it may have been adjudicated as against only part of the other claims from the same source of supply.

5. Soils of the Arid and Semi-arid Regions.—Soil may be defined as disintegrated and decomposed rock into which has been incorporated more or less organic matter derived from plant and animal life. Soils are of various chemical and mechanical composition like the rocks from which they are derived. They are popularly classified according to their relative sand and clay content, as light or heavy, sandy or clay. To this classification there is sometimes added, in arid regions, a third class, viz., alkali soils, which are almost always of the heavier type.

In general it may be said that the soils of the irrigated sections of the United States are deep, of high fertility and uniform texture, contain large quantities of lime and potash, are low in humus content and phosphorus but fairly well supplied with nitrogen. They allow water to penetrate readily to great depths, contain less clay and more sand than humid soils and consequently do not bake so readily. Arid soils have much better natural drainage than humid soils but due to their great depth, plant food is not leached out into the ground water and thus lost. The high per cent. of lime in arid soils prevents sourness, encourages bacterial life, makes some plant foods more available, and aids in converting organic matter into humus. The hard, impervious, non-penetrable clay subsoil of humid sections is almost unknown in arid regions but hardpans are found in many localities. These hardpans are the result of a concentration of lime and to a limited extent of clay at a depth

below the surface corresponding to the limit of average penetration of the seasonal precipitation. The precipitation, penetrating the soil to approximately the same depth each yeai carries in suspension and in solution some of the finer material and lime found in the top soil. These substances are deposited at about the same depth from year to year and by physical and chemical means form the hardpan. This hardpan is almost always dissolved and destroyed under irrigation.

To describe the chemical composition of the average arid soil it will probably be well to compare it with the average composition of soils from humid sections.

TABLE No. 6

Chemical Composition of Average Humid and Arid Soils. (After Hilgard)

Number of samples	Insoluble residue	Partial percentage composition					Humus
		Soluble silica	Alumina	Lime	Potash	Phosphoric acid	
Humid 696.....	84.17	4.04	3.66	0.13	0.21	0.12	1.22
Arid 573.......	69.16	6.71	7.21	1.43	0.67	0.16	1.13

From the above table it is observed that the arid soil contains more soluble matter and more of the mineral and plant

TABLE No. 7

Class of soil and location	Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
Millimeters.............	2–1	1–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.005	0.005–0
Salt River clay loam, Ariz.	Tr.	0.12	0.20	3.80	12.78	42.30	41.00
Imperial fine sand, Cal...	0.00	Tr.	1.20	42.20	38.00	15.00	3.58
Imperial clay loam, Cal...	Tr.	0.30	0.34	1.92	3.64	53.90	39.80
San Joaquin Valley sandy loam, Cal.............	1.60	13.40	13.70	27.10	11.90	21.00	10.90
Silty clay loam, Colo.....	0.00	0.30	0.40	4.30	7.30	64.10	23.50
San Luis sandy loam, Colo	8.96	22.08	10.26	15.54	11.70	19.84	11.26
Yakima sandy loam, Ida.	1.50	14.50	15.90	39.60	13.10	8.40	7.10
Colby silt loam, Kansas	0.00	0.20	0.20	0.60	21.30	66.10	11.60
Bozeman silt loam, Mont.	0.20	0.70	0.50	1.40	8.10	71.30	17.80
Finney fine sandy loam, Nebr..................	0.10	0.30	0.30	10.00	48.60	35.10	5.50
Lahontan sandy loam, Nev.	3.60	10.30	13.60	30.60	18.60	14.20	9.40
Morton loam, South Dakota	0.20	0.10	1.10	16.00	20.70	39.10	22.40
Amarillo sandy loam, Texas.................	0.40	7.90	18.50	44.20	13.30	11.00	7.90
Jordan loam, Utah.......	0.36	0.90	0.60	2.24	14.64	43.08	37.80
Yakima sandy loam, Wash.	1.50	3.08	2.06	5.96	34.82	45.04	3.98
Quincy silt loam, Wash...	0.00	0.50	1.30	9.30	32.60	51.80	4.40
Laramie sandy loam, Wyo.	2.80	12.60	14.10	29.80	19.16	13.10	8.40

foods with the exception of humus. Hilgard determined, however, that the low humus content is partly compensated by the much higher nitrogen content of the humus in arid soils as compared with the humus of soils in humid sections.

The preceding table was compiled from the published reports of the Bureau of Soils, U. S. D. A. and gives the mechanical analyses of typical soils in various irrigated valleys throughout the arid and semi-arid belt.

The soils of the arid region will average about 50 per cent. of open space. According to Lyon and Fippin the pore space of various soils under field conditions is about as follows:

	Per cent.
Clean sand	33.5
Fine sand	44.10
Sandy loam	51.00
Silt loam	53.00
Clay loam	54.00
Clay	56.00

"The effect of irrigation upon arid soils" according to Professor W. W. McLaughlin of Utah, "is to dissolve plant food for use of the plants, to break up hardpan, to cause the clay to become troublesome, and in case of gypsum soils to cause them to settle. In alkali soils the results of irrigation may be beneficial or detrimental, depending upon drainage. The water, in penetrating an alkali soil dissolves the salts and carries them downward into the soil. After each irrigation part of the water previously applied is drawn upward by evaporation and transpiration and the salts are deposited at or near the surface. If this process be continued there may finally be such a concentration of salts at the surface as to injure or entirely prevent plant growth and the land is then said to be 'alkalied.'"

In selecting a soil in the arid region the following points should be kept in mind: A growth of sagebrush, bunch grass, tree and brush growth are indexes of a fertile soil, while a growth of shad scale, salt grass and other alkali-tolerating vegetation indicates a soil which, while it may be fertile, may contain alkali salts in such quantities as to become troublesome under irrigation and especially unless great care is taken in the application of water. The mechanical appearance of the soil, the way it feels in the hand, its taste, etc., aid in determining the probable difficulty in

securing and maintaining proper tilth. The depth of the soil either to hardpan or to bedrock should be determined, as upon this depth will depend to some extent the lasting power of the soil. The natural drainage and the situation of the land with respect to probable location of canals and other irrigated lands is an important point. It is a fact that in all of the older irrigated sections, some of the lower lying lands that were in the early days most productive have, with the development of irrigation, become water-logged or alkali-ridden. Not all soils are adapted to all crops. Some soils are adapted to one crop but not to another. This is illustrated in the selection of soils for peach growing. If the peach tree is planted upon heavy strong soils or soils naturally very damp, the trees will grow very rapidly but the fruit will be inferior in every way. Numerous other illustrations could be cited.

6. Soil Moisture.—All substances contain moisture under normal conditions. Scientists have divided all moisture contained with the soil into three general classes with respect to its physical properties, namely, hygroscopic, capillary and gravitational. Only by artificial heating can soils be rendered water-free.

Hygroscopic.—Water which in nature clings to all matter, and varies in amount with the temperature, dampness of the air, sunshine, and other less important factors, is called hygroscopic. That it is of no direct value to plants is now generally conceded. According to Hilgard, arid region soils will absorb water in a saturated atmosphere equal to 5.5 per cent. of their dry weight. This amount represents their maximum hygroscopic capacity, but the actual content of water in this form is usually much less. Under Great Basin conditions, the hygroscopic content is reported by Widtsoe to vary from 0.75 to 3.50 per cent., averaging approximately 1.5 per cent.

Capillary.—Under normal field conditions, every minute soil particle is invested with a very thin film of moisture. Water thus held in soils is called capillary. One gram of a coarse sandy soil according to Lyon and Fippin, contains 3,276,000,000 particles, while the same weight of silt loam and of clay soils contain 9,639,000,000 and 19,525,000,000 particles in the order named. Provided these particles were spherical, their surface

area in square feet per pound of soil would be 405, 1314, and 2000 respectively. These figures clearly indicate how soils can contain large quantities of capillary water, even though the film about each particle is very thin.

Moreover, it is evident that as the soil grains decrease in size, and the number and surface area of the particles per unit of volume increase, the moisture capacity should likewise increase. This is in fact the case. Ordinary plants get all of their water from the capillary form.

GRAVITATIONAL.—Gravitational water or that which percolates through the soil due to the force of gravity, supplies the deficiency in the capillary content caused by plant absorption and evaporation. Prof. O. W. Israelsen of the University of California states that "irrigation should be so controlled that all of the gravitational water added to the soil will be changed to the capillary form before it is lost to plants by passing far beyond their root zone or into the ground-water table. Each farmer can, by the use of a soil auger make enough borings after irrigation to determine for his particular soil the normal depth of penetration of a given amount of water applied."

The relation of the classes of soil moisture and their availability to plants is well illustrated in the following diagram after Lyon and Fippin.

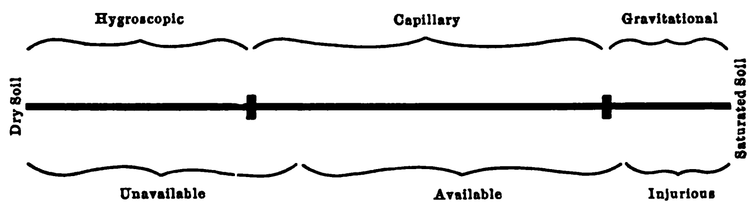

FIG. 1.—Forms and relationship of soil moisture.

DETERMINING SOIL MOISTURE CONTENT.—Soil moisture, or moisture content is expressed in per cents. of the weight of dry soil. This is determined as follows: A sample of wet soil is dried in an oven at a temperature slightly above 100 degrees C. or 212 degrees F. until no further loss occurs under this temperature. The period of heating required is dependent upon the quality of the soil and the wetness of the sample and will usually take

from 5 to 12 hours. The per cent. of soil moisture or moisture content is computed thus:

$$\frac{\text{Loss of weight in drying}}{\text{Weight of dry soil in sample}} = \text{Per cent. moisture or moisture content.}$$

PROPER PERCENTAGE OF SOIL MOISTURE.—Irrigators may get a general knowledge of capillary moisture content by simply air-drying a sample of soil and computing percentage as above. Neither method, however, gives accurate knowledge of the water which is available for plants. This may be closely approximated by deducting from the per cents. obtained by the method first outlined, the per cents. at which ordinary plants wilt in soils of the class tested. The "wilting coefficient" for various soils as determined by Messrs. Briggs and Shantz are quoted below, but it should be remembered that under normal conditions, plants can derive moisture for plant growth at points somewhat below those quoted here.[1]

Coarse sand	0.9	Loam	13.1
Fine sand	3.2	Clay loam	15.9
Sandy loam	7.0	Clay	25.2
Fine sandy loam	10.7		

Lack of moisture limits plant growth over about 65 per cent. of the earth's surface, while crop production is also prohibited on large areas by an excess of water. The importance of an adequate supply of moisture and the bad effects of too much are considered in other parts of the book. It is apparent that plants differ greatly in their requirements for water. These requirements are the results of various factors, such as temperature, sunshine, shade, humidity, and the plant food available in the soil. It is possible for man to exert partial control over all these factors. Soil fertility, however, which plays a very important rôle in water requirement is almost entirely under the irrigator's control. If farmers desire a high efficiency in the use of moisture, they must maintain an adequate supply of plant food in their soils.

Soils should not be too wet or too dry. Either extreme should be avoided if possible. It is well known that plants

[1] Bul. 230, B. P. I., U. S. D. A.

which are grown in very moist soils waste water. Moreover, evaporation losses from such soils are a maximum. Paradoxical as it may seem, plants are equally wasteful of water where the moisture content of the soil is very low. Briggs and Shantz have assembled data from a large number of experiments which indicate that the water requirements for every pound of dry matter produced increase as either extreme in moisture content is approached. Such relations have also been observed in the results of field experiments at Davis, California, conducted under the auspices of the Office of Experiment Stations in cooperation with the State Engineering Department and the University of California. Soils which are kept moist absorb water much more readily than those which have been allowed to become very dry and in very dry soils bacteria are not active. It is important, therefore, to prevent excessive drying out in order to allow plants to use water efficiently, to provide for continuous plant food formation by bacterial action, and to cause water to be readily absorbed.

In deep loamy soil, according to Widtsoe, a total moisture content of about 18 per cent. is the most desirable for such crops as wheat, oats, barley, alfalfa, sugar beets and potatoes. This optimum per cent. varies with the soil, decreasing as the soil becomes lighter and increasing as it becomes heavier. The minimum moisture content desirable, varies in the same manner but should approximate at least 12 per cent. for a deep loam.

7. Movement of Soil Moisture.—The forces which produce motion in the water of soils are the same the world over. It is also true that the sources from which the water is derived and the manner in which it is distributed over the land exert an influence in the direction and volume of subsurface flow. In a humid region the clouds are the main source of soil water. This falls as rain or snow with fair uniformity over the entire surface. In an irrigated district with its light rainfall and heavy evaporation, the main source of water is the artificial canal which delivers water to smaller distributaries on benches more or less distant from natural streams. A large part of the water so distributed passes under the forces of gravity and capillarity through the upper stratum of soil into the subsoil. One of the first effects of this movement of water is to raise the ground water

level. This may be observed by noting the sudden rise of water in a well located near a field which is irrigated. After a little time the greater part of the excess water which caused the rise of the water table finds its way through the subsoil to lower levels. This is known throughout the West as seepage water.

RATE of FLOW of SEEPAGE WATER.—The rate of flow of seepage and underground waters generally depends upon a number of conditions. The chief of these are (1) the available head or gradient, (2) the relative porosity of the soil and (3) the temperature of the soil and water. In the following table, compiled from Water Supply Papers Nos. 67 and 140, U. S. Geological Survey by Prof. Chas. S. Slichter, the velocity of flow is based on a fall or grade of 100 feet per mile, a porosity of 32 per cent. and a temperature of 50 degrees F.

TABLE No. 8

Kind of soil	Diameter of soil grains, mm.	Velocity	
		In feet per day	In miles per year
Silt	0.01	0.0038	0.00026
	0.04	0.0590	0.00408
Very fine sand	0.05	0.0923	0.00638
	0.07	0.1808	0.01250
	0.09	0.2989	0.02066
Fine sand	0.10	0.3690	0.02551
	0.15	0.8322	0.05753
	0.20	1.476	0.1021
Medium sand	0.25	2.305	0.1594
	0.35	4.520	0.3125
	0.45	7.471	0.5165
Coarse sand	0.50	9.224	0.6377
	0.65	15.57	1.077
	0.80	23.62	1.633
	0.95	33.30	2.302
Fine gravel	1.00	36.90	2.551
	3.00	332.1	22.96
	5.00	1067.0	63.77

CAPILLARY MOVEMENT of SOIL MOISTURE.—Capillary movement may be readily observed in furrow irrigation where a small stream of water is run in furrows several feet apart. If the flow in each furrow were not acted upon by any force other than gravity the water would tend to sink vertically downward. While

there is motion in this direction the moisture also spreads sidewise so as to moisten in time all the intervening space between the furrows. In the case of deep furrows, such as are used in the irrigation of potatoes, the water is not only drawn sidewise but upward, thus overcoming the pull of gravity.

The action of this natural force is of paramount importance to agriculturists in general, and especially to irrigators. The latter have to devise ways and means to moisten the soil artificially and without the aid of this force it would be impossible to distribute water in soils so effectively or to maintain the proper amount of moisture within the root zone of plants. Thus, when a relatively dry soil lies next to a wet soil the excess of film water in the latter is gradually drawn to the former. Again, when the rootlets of a plant absorb the moisture in the soil around them the deficiency is made up by drawing moisture from wet soils. So, too, as the top layer of soil is robbed of its moisture by evaporation, a fresh supply is raised from below. Hence it is apparent that this force not only aids the irrigator to distribute water in soils but acts as a great equalizer of soil moisture.

Capillary force or surface tension as it is sometimes called, is usually compared and measured by placing the lower ends of columns of typical soils or soil ingredients in contact with water and noting the vertical height to which water will rise through the material in a given time. The movement of soil moisture due to this force may be measured by determining the amount of water which is raised, say a foot high, through the material in a given time. When the lower end of a column of air-dry soil is brought into contact with water, the rise of the water in the soil is at first quite rapid. This is seen in Table 9. After the end of the first day or so the rise is less rapid as is shown in Table 10, and in time reaches a height beyond which it does not rise.

TABLE NO. 9

Capillary Rise of Moisture in Soils. (Hilgard)

Class of soil	Clay	Silt	Medium sand	Sandy loam
Rise of moisture......	Inches	Inches	Inches	Inches
End of 1 hour........	0.5	11	10	7
End of 1 day.........	2.0	43	13	17
End of 6 days........	8.0	65	22	23
End of 10 days.......	13.0	72	23	25

TABLE No. 10

Height of Rise of Water in Dry Soils of Different Texture. (Lyon and Fippin)

	Time							
	Min.	Hours		Days				
	15	1	2	1	3	8	13	19
	In.	In.	In.	In.	In.	In.	In.	In.
Silt and very fine sand	2.7	4.7	7.0	20.0	30.0	45.0	52.0	56.0
Very fine sand	7.6	10.0	12.4	21.0	23.0	26.0	27.5	28.5
Fine sand	9.0	9.5	10.0	11.6	13.0	14.3	15.2	16.0
Coarse and medium sand	5.8	6.0	6.3	7.5	9.0	10.0	11.5	12.5
Fine gravel	4.0	5.0	5.3	6.4	8.0	9.0	10.0	10.8

CHAPTER III

THE NECESSARY EQUIPMENT AND STRUCTURES

8. Equipment for the New Settler.—Many advertisements for the sale of irrigated lands state or leave the impression that men with but little capital and experience can easily make a success upon such lands. While it is true that the ability to do hard work, a willingness to suffer privations and a determination to succeed greatly supplement a small bank account, yet there are many demands for capital which must be met. Before purchasing, the prospective settler should either have sufficient money to meet such demands or know from whence he may secure it when needed.

The first expenditure required of the prospective settler is the first payment upon the land. This varies in price according to locality and the cost of developing the project. Prior to moving to the land a house should be built for habitation. The settler may provide a temporary structure but this should be fairly well built since it may have to do service for several years. The size and cost of such a house and its furnishings will depend to a large extent upon the size of the family. In addition a barn will be required for whatever live stock is purchased. The settler should provide himself with a good team and wagon complete with harness, an extra horse, a milch cow, two pigs and fowls.

For reclaiming, leveling and putting the land under cultivation a plow, harrow, leveller and other implements will be required. While not absolutely necessary the settler will find that the purchase of a few miscellaneous tools for working in wood and metal will prove a great convenience. Some implements, such as a mower and hay rake can, no doubt, be rented from some neighbor whenever needed.

Fencing the entire place may be out of the question for the first year or two but should be done as soon as practicable

in order to furnish pasturage for the cow thus reducing the feed bill to some extent. At any rate enough fencing should be provided to build a feed coral at the barn.

The settler should move to the farm some time during the fall or early spring, preferably the latter, before the cropping season begins in order to clear, plow and level a portion of the land for cultivation. This tilling of the soil will involve the purchase of seed and the yields for the first year will barely pay expenses of cropping and in many cases barely furnish enough seed for the increased acreage the following season. As the returns from the first season will be light the settler must provide provisions for himself and family and feed for the live stock during the first season and the greater portion of the following season.

It is very doubtful whether the return from the crops will furnish a living to the settler and meet the expenses incurred by such improvements as will be required from time to time within several years. Usually on most projects the second payment with deferred interest falls due at the end of the first season and this money must be derived from outside sources.

At some certain date during the year, fixed by statute, the settler becomes subject to taxation for both personal property and real estate. Lands located upon Carey Act projects become taxable as soon as final proof is made, while those located upon Reclamation projects of the United States are not taxed until title is obtained. Assessments to provide for maintenance and operation charges for irrigation works must, of course, be met each year whether the land is patented or not.

No title to the land can be acquired until all payments have been made. As only equity to the land can be given as security for loans interest becomes high and credit limited making loans on real estate held in equity hard to float. Thus payments with deferred interest can not be raised by making loans on the place but must be derived from outside sources until such time as the farm has reached a paying basis.

Summarizing, the settler will require money to meet the following expenditures:

First payment on the land.
House.
Domestic water supply.
Barn.
Two or three horses with wagon.
Milch cow.
Two pigs.
Fowls.
Plow.
Land leveler.
Harrow.
Miscellaneous tools.
Taxes—personal and real estate.
Fencing—at least enough for corral,
Provisions for two seasons.
Feed for live stock for greater portion of two seasons.
Seed for seeding land.
Annual payments and deferred interest until farm reaches paying basis.

All of the above expenditures involve a supply of ready cash which can be drawn upon as needed. Due to the range of prices in the local markets throughout the different sections of the country the amount of available money required will vary for the various sections. H. C. Diesem, Irrigation Engineer of the Department of Agriculture, who has had a varied experience in dealing with new settlers believes that a prospective settler going upon a 40-acre farm in a newly developed section should have an available fund of from $1500 to $3000 with which to meet expenses as they may arise.

9. Laying Out a Farm under an Irrigation System.—"The governing factor in laying out a farm which is to be irrigated" according to F. L. Bixby, Irrigation Engineer of New Mexico, "consists in providing proper facilities for the ready and uniform distribution of water to all parts." Since the location and cost of permanent farm ditches depend to a large degree on surface configuration, it is a saving of money in the end to have a survey and topographic map made of the entire tract. If this can not be done surface levels should be taken to fix the proper location of the fields, ditches, and other permanent features. The supply ditch from the main canal or from one of its branches should be as short and as large as possible. The main points to be kept in mind in fixing its location are to convey the water with the least loss to the highest part of the farm if practicable, to run parallel to fence lines or field borders, to avoid use of syphons, flumes or dikes and to adopt a suitable grade. The capacity of the supply ditch, as well as the capacity and direction

of the farm ditches, depend on the size of the farm and fields, the method to be followed in irrigating, the kind of crops which are likely to be raised and other considerations.

Owing to the nature of land surveys, irrigated farms usually comprise some even multiple of the 10-acre tract. This unit also forms a convenient size for fields where the topography will admit of such an arrangement. If too large for a field, a 10-acre tract can be subdivided in the direction in which it is irrigated. The width or length (660 feet) of this unit of area is about as long a distance as water should be run in furrows. In laying out small tracts of land for suburban settlers in irrigated districts the rectangular form has some advantages. Dr. H. C. Gardiner of the Anaconda Copper Mining Company, in subdividing lands for this class of occupants on the outskirts of Anaconda, adopted the arrangement shown in Fig. 2. This

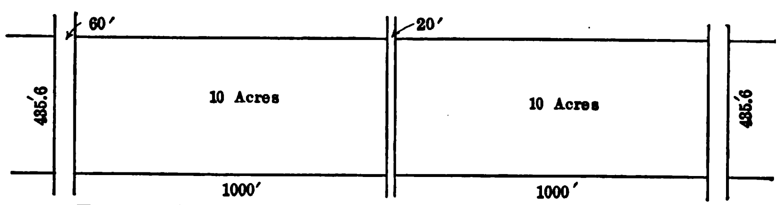

FIG. 2.—Arrangement of tracts for suburban irrigated farms.

lessens the number of roads or streets, facilitates the distribution of water, is better adapted to the rotation of crops and removes to a greater distance from the residence the ugly and unwholesome features of farm life.

In laying out fields and permanent farm ditches, one should not overlook crop rotation. The same field may be in root crops one season, in cereals the next and in a legume the third. With the exception of fruits, vines, and a few other crops, rotation of one kind or another is quite generally practised under irrigation and it is well to plan farms at the start so as to conform to this use. Owing to the wide variation of soils on some farms and to the further fact that particular soils are adapted to particular crops, it is well to set aside a certain field for a special crop, such as fruit trees. The Director of the state experiment station in which the farm is located may be with profit consulted on matters pertaining to soils, crops and climate.

Farm Buildings.—Good drainage and sanitation are prime requisites in fixing the location of a farm home. Such questions as facing the public highway, exposure to high or chilling winds, the advantage of a beautiful outlook and accessibility to other parts of the farm, although of much importance in themselves, occupy a second place. Sometimes a part of the farm is too high to be watered by a gravity ditch and this cheap and dry part may be utilized for farm buildings and yards. This proves a good selection providing water can be pumped or otherwise secured for domestic, lawn and garden purposes. Farm houses should be set back at least 100 feet from roads or bare ground to avoid the discomfort of drifting dust and to assure an attractive setting of lawn and shrubbery. Whatever the source of the domestic water supply, whether from a well, cistern or spring, it should be carefully guarded from contamination. A water-tight cess-pool or septic tank should be provided but if this can not be built great care should be used to protect sewage from flies and to convey it beyond the possible reach of the water supply through surface channels or underground percolation. This highly important feature is commonly overlooked as may be seen in the careless location of sewage drains and outbuildings. Its careful observance is an excellent preventative of typhoid and similar diseases. The homestead should likewise be protected from prevailing winds by a grove of trees of the variety best suited to the climate and soil. Poplar or cottonwood, and in localities of little frost, eucalyptus, when well watered, will grow rapidly. These may alternate with the slow-growing elms, box elders, oaks and peppers. Good roads and lanes lined with shade trees, not only enhance the value of the farmstead but add greatly to its attractiveness. The farm home and its surroundings in an irrigated district need not be expensive in order to be beautiful. Where there is an abundance of rich soil, a ready supply of water and a favorable climate, it is easy to convert a dreary abode into an attractive residence. Green grass soon covers the drifting sands, a climbing rose or a vine conceals an ugly exterior and the foliage of shrubs and trees affords shelter from the rays of the western sun.

10. Farm Ditches.—Farm ditches are either permanent or temporary. The former include the main supply ditch to the

farm and its various branches to subdivisions of the farm. The latter are confined to the small distributaries in each field and are renewed for each crop.

LOCATION.—The chief features to be considered in locating permanent farm ditches were pointed out in Art. 9. It may be stated here by way of emphasis that too much care can not well be given to this subject since faults of location in such channels affect the whole farm. The most common mistake made by farmers is to lay out and build a system of ditches for a part of the farm without regard to the irrigation of the remainder. Since these are considered temporary in character little attention is paid to them but after the lapse of years it is found both difficult and costly to abandon the old and begin anew.

GRADE OF DITCHES.—The quantity of water which a ditch will carry depends fully as much on the fall or grade as on its size. The two elements should be considered together. When conditions are such that one can adopt a suitable grade the chief points to consider are the volume to be carried and the nature of the soil. The smaller the volume the greater the grade required. In a small ditch capable of carrying 50 miner's inches a fall of 2 inches to the rod would produce a velocity of 2 feet per second, while in a ditch capable of carrying 950 miner's inches the fall required to give the same velocity is only 1/4 inch to the rod. In fine sand or sediment a flat grade is required to prevent scouring. A mean velocity of 1 foot per second is sufficient for such material. In hard gravel or hard clay or in a mixture of these, a velocity of 3 feet per second can be used without eroding the bottom. In ordinary materials, ranging from sandy or gravelly loams to clay loams, a grade may safely be adopted which will produce a mean velocity of 2 to 2 1/2 feet per second. On a farm with little fall the grade can not exceed that of the land. On rolling land or where the slope is steep a suitable grade for ditches can usually be found by running them across the slopes rather than directly down them. When excessive grades can not be avoided by winding around the high places the speed of the water may be checked at intervals by the insertion of drops or a rough pavement of cobble stones loosely laid. Check boards are convenient to direct water into

laterals, and at a slight additional expense they may be combined with a permanent drop. Considering the ditch alone it is preferable to use a grade which for its size will give a velocity just safely less than will cause cutting in the type of soil through which it is to be built.

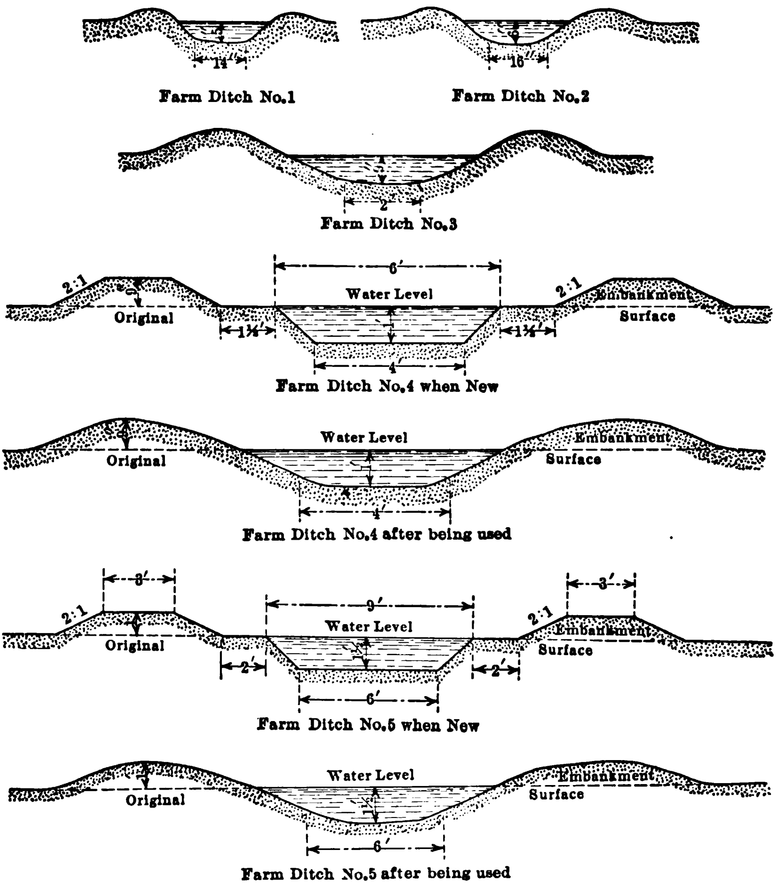

FIG. 3.—Farm ditches of various capacities.

FORM OF DITCHES.—The principal function of both the permanent and temporary ditches is to get water on the land quickly and easily. To do this the form of the ditch should be such that the water surface in the ditch is kept above the ground to be

covered. Ditches should not be allowed to cut deeply into the ground so that diversion is hindered. When being built they should be well banked so that the turnouts can be made without having to raise the water above safe limits on the banks above. The form of the cross section of a ditch depends largely on its method of construction. Small ditches made with a V crowder (Fig. 5), are generally triangular in shape when built. If the velocity is not such that scour will occur these usually become rounded as shown in Ditches Nos. 4 and 5 (Fig. 3).

The larger ditches are usually constructed with a scraper working across from side to side making a bank on both sides in nearly level ground and on only the lower side in side-hill work. Such ditches are best built with curved cross section as the squaring to a regular trapezoidal shape does not give advantages in proportion to the work required. In ditches made wide enough for a slip or scraper to be run along in the direction of the length of the ditch, the trapezoidal shape is as easily built as the curved. Typical shapes and dimensions for small

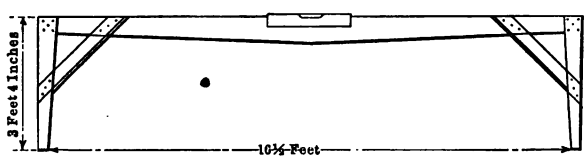

FIG. 4.—Home-made level for locating ditches.

ditches are shown in the accompanying cuts, the ditches shown being those for which the tables of capacity given later are computed.

CAPACITY.—The capacity needed depends chiefly on the manner of delivering the water and the methods used in applying it. It also depends, but to a less extent, on the size of the farm, the duty of water, the nature of the soil and the crops raised.

FLOW OF WATER IN FARM DITCHES.—In the table which follows (Table No. 11) the flow in each of the five types of farm ditches previously shown (Fig. 3) has been figured for different grades. These grades are intended to cover ordinary conditions on most farms and are expressed in three ways: First, in inches and fractions of an inch per rod; next in feet per 100 feet; and, lastly, in feet per mile. The mean or average velocity of the

water in each kind of ditch having a given grade is also given, as well as the discharge in cubic feet per second and its equivalent in miner's inches under a 6-inch pressure head, about 40 of such inches being equal to 1 cubic foot per second. Thus in farm ditch No. 3 a grade of 1/2 inch per rod produces a discharge of 168 miner's inches, but when the grade is increased to 3/4 inch per rod the discharge is 207 miner's inches.

TABLE No. 11

Table giving the Mean Velocity and Discharge of Ditches with Different Grades. Lateral ditch with bottom width of 14 inches (ditch No. 1)

Grade			Mean velocity in feet per second	Discharge	
Inches per rod	Feet per 100 feet	Feet per mile		Cubic feet per second	Miner's inches under 6-inch pressure head
1/2	0.25	13.33	1.01	0.67	27
3/4	0.38	20.00	1.23	0.81	32
1	0.51	26.67	1.42	0.93	37
1 1/4	0.63	33.33	1.59	1.05	42
1 1/2	0.76	40.00	1.75	1.16	46
2	1.01	53.33	2.04	1.35	54
2 1/2	1.26	66.67	2.28	1.50	60
3	1.51	80.00	2.50	1.64	66
3 1/2	1.77	93.33	2.70	1.78	71
Lateral ditch with bottom width of 16 inches (ditch No. 2)					
1/4	0.13	6.67	0.82	0.80	30
1/2	0.25	13.33	1.16	1.00	42
3/4	0.38	20.00	1.42	1.30	52
1	0.51	26.67	1.64	1.50	60
1 1/4	0.63	33.33	1.84	1.70	67
1 1/2	0.76	40.00	2.02	1.80	74
1 3/4	0.88	46.67	2.18	2.00	80
2	1.01	53.33	2.34	2.10	86
2 1/2	1.26	66.67	2.61	2.40	96
Lateral ditch with bottom width of 2 feet (ditch No. 3)					
1/8	0.06	3.33	0.79	2.08	83
1/4	0.13	6.67	1.13	3.00	119
1/2	0.25	13.33	1.60	4.20	168
3/4	0.38	20.00	1.97	5.20	207
1	0.51	26.67	2.28	6.00	239
1 1/4	0.63	33.33	2.57	6.80	270

TABLE No. 11 (*Continued*)

Table giving the Mean Velocity and Discharge of Ditches with Different Grades. Lateral ditch with bottom width of 4 feet (ditch No. 4)

Grade			Mean velocity in feet per second	Discharge	
Inches per rod	Feet per 100 feet	Feet per mile		Cubic feet per second	Miner's inches under 6-inch pressure head
1/16	0.03	1.58	0.84	4.20	168
1/8	0.06	3.33	1.08	5.40	216
1/4	0.13	6.67	1.54	7.70	308
3/8	0.19	10.00	1.89	9.50	378
1/2	0.25	13.33	2.20	11.00	440
5/8	0.31	16.67	2.45	12.20	490
3/4	0.38	20.00	2.69	13.40	538

Lateral ditch with bottom width of 6 feet (ditch No. 5)

1/16	0.03	1.67	1.03	11.6	464
1/8	0.06	3.33	1.48	16.7	666
3/16	0.09	5.00	1.82	20.5	819
1/4	0.13	6.67	2.11	23.7	950
5/16	0.16	8.33	2.35	26.4	1,058
3/8	0.19	10.00	2.58	28.0	1,121
7/16	0.22	11.67	2.80	30.5	1,260

INSTRUMENTS NEEDED IN LAYING OUT DITCHES.—In laying out supply ditches an engineer's level and rod are the most convenient instruments. The distances may be estimated by

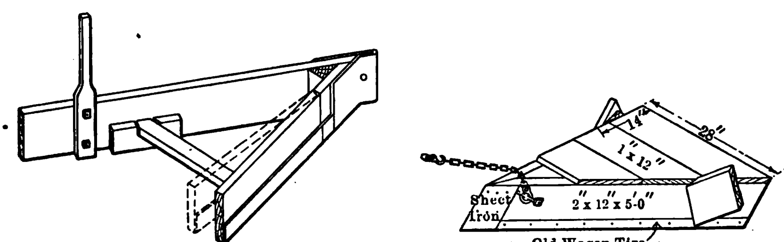

FIG. 5.—V-crowders used in building farm ditches.

pacing. When such instruments are not available, a useful substitute consists of an ordinary carpenter's spirit level attached to a portable wooden frame, a sketch of which is shown in Fig. 4. When first made and placed on a level surface the bubble should come to the center of its run. Then one leg is shortened by the amount of the grade per rod (see Table of Grades).

The device is operated by one man, who first places the shorter leg at the surface of the water in the main canal or supply ditch and swings the other end around until the bubble comes to the center. The location of the longer leg is then marked by a helper, who carries a shovel and removes part of a shovelful of earth. The level is then carried forward until the shorter leg occupies the position vacated by its mate, when a second mark is made. This operation is repeated until the line is laid out and a furrow is run connecting all of the temporary marks.

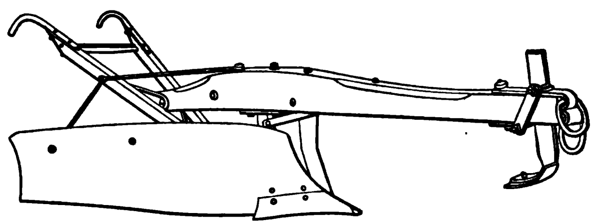

Fig. 6.—Wing plow.

Construction.—Usually for the construction of farm ditches the ground is plowed to the width desired. With small ditches a lister or ditch plow may be run through once and the ditch shaped by hand or with a small log crowder. With larger ditches as many furrows as needed can be plowed and a V crowder such as is shown in Fig. 5 used to shape the ditch and pile the earth in the banks. By varying the shape of the V or by the driver and helper shifting their weight in riding the crowder, the ditch can be shaped to almost any desired form. A wing plow such as is shown in Fig. 6 can be used to plow and clean the ditch at the same time. For larger ditches graders can be used. A greater range of adjustment of the blade is needed for ditch work than for leveling.

In case it is necessary to build the ditch in fill over low places, the necessary dirt for the fill can be brought from the adjoining ground and the ditch shaped on its top as in level ground.

If possible ditches should be built some time before use so that the banks may have time to settle. In case the banks are still soft when water is first run great care should be taken to avoid breaks.

MAINTENANCE.[1]—Maintenance of farm ditches aside from the repairs to structure is principally of two kinds, the prevention or removal of weeds and the cleaning out of silt and aquatic growths. In the case of weeds, prevention where practicable is preferable. Irrigation waters usually carry weed seeds. If the grade of the farm ditch is such as to give as high a velocity as in the lateral from which the water is received, the weed seed and silt can be largely carried on through to the fields. More trouble is generally experienced from weeds on ditches with low velocities. The planting of alfalfa or other crops on the ditch banks is a preventive measure. The cutting of weeds before they seed at slack times is another. In some cases aquatic growths occur which reduce the carrying capacity to such a degree that irrigation must be stopped and the ditch cleaned. These growths may be grass growing in the water or on the banks and drooping over into the ditch or they may be trailing moss, water cress, or other forms of water plants. In ditches in use only a part of the time the moss is usually killed during the periods the ditch is dry. The grasses, however, grow best at such times in the wet mud of the ditch bottom. In farm ditches the grasses can be mowed with a hand scythe without having to shut off the water. Regular and smooth banks will allow the use of the mowing machine for a large part of the weeds and grass leaving only the finishing for the scythe. The cleaning of ditches is generally a necessity in the spring whether the ditch is one that scours or one that silts. In a ditch which scours, the undercut banks will need shaping. In a ditch which silts, the deposits will need to be removed. This may be done either by hand shoveling where small in amount or by any of the methods described for the original construction.

11. Irrigation Structures for the Farm.—The structures which may be used on an irrigated farm in connection with the use of water include headgates, measuring devices, flumes, pipes, culverts, wells, cisterns, reservoirs, etc. Many of these have been described under other headings and need not be considered here.

[1] On this subject as well as that of farm ditches in general the writer has drawn from the experience of S. T. Harding of the University of California.

DELIVERY GATES.—A headgate is needed to control the flow from the main or branch canal into a private ditch. The gate and its framework, together with the pipe or box which conducts the water out of the canal into the farmer's ditch is sometimes termed a turnout. A structure of this kind should meet the requirements of both the canal company and the water user. The interests of the water company demand that it be secure, water-tight when closed, large enough to admit the necessary

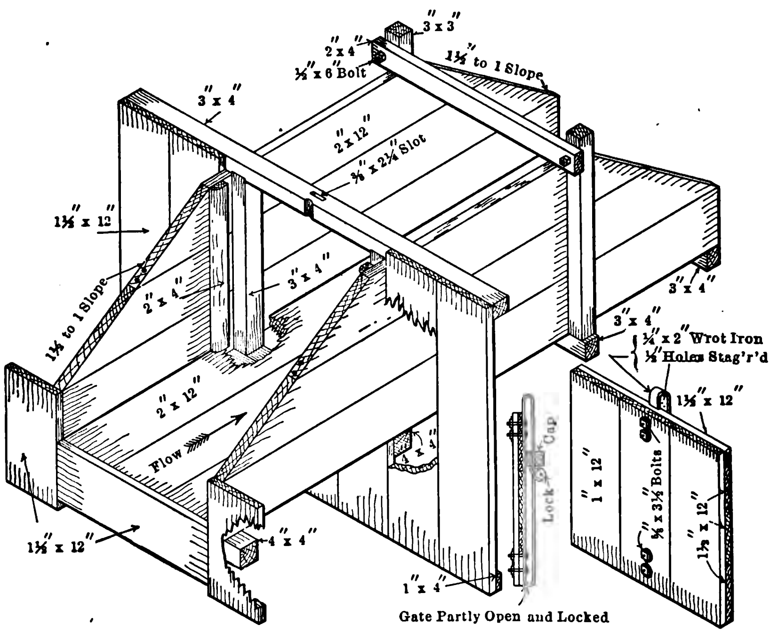

FIG. 7.—Delivery gate to farm lateral.

flow and so designed that it will not discharge after adjustment more than a certain fixed quantity of water. The water user is likewise interested in having a substantial structure of ample size but in addition he desires it to be designed in such a way that he can, when he chooses, close it partly or altogether. The wooden headgate, Fig. 7, designed by F. C. Scobey, is intended to be connected with a wooden box or flume.

Another type of wooden headgate with screw lift designed by

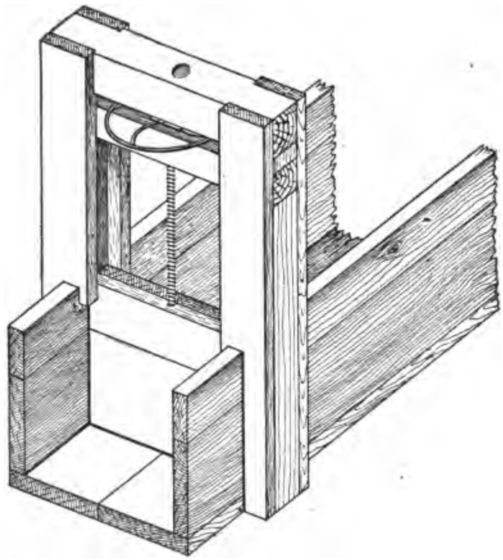

Fig. 8.—Another type of wooden gate.

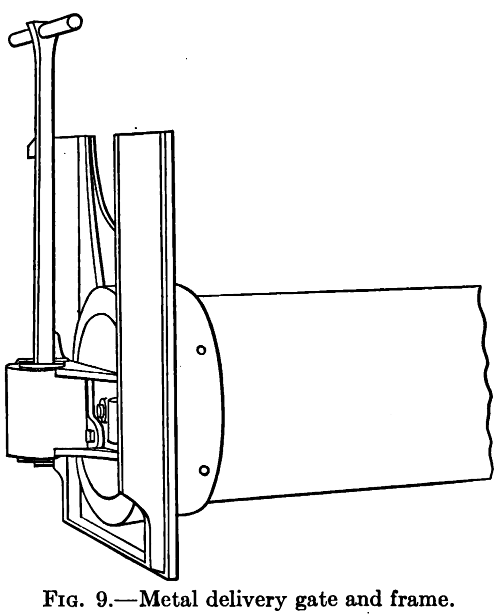

Fig. 9.—Metal delivery gate and frame.

J. L. Rhead and used by the writer on the Bear River Canal laterals is shown in Fig. 8.

A more durable delivery gate made by the Kellar-Thomason Mfg. Co., of Los Angeles, Cal., consists of a metal gate and frame attached to a short line of pipe laid beneath the canal bank. The pipe may be vitrified clay, concrete or steel. Fig. 9 shows a connection made with a steel pipe.

One of the latest types of delivery gates in use in the Imperial Valley, California, for admitting water to borders is made by moulding a concrete head on a joint of concrete pipe the opening being regulated by a galvanized iron gate held in place by

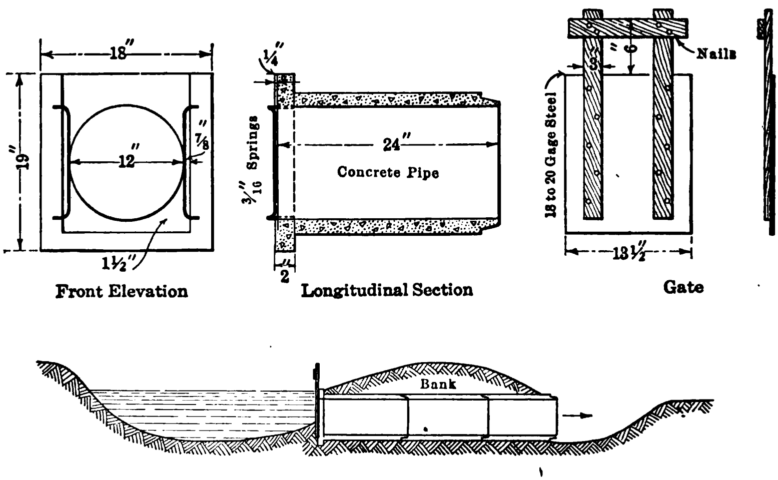

Fig. 10.—Delivery gate in use in Imperial Valley, Cal.

springs. The gate is manipulated by an iron handle or wooden frame fastened to the gate. Fig. 10 shows the essential features of this design.

The chief points to be considered in the installation of such structures are: (1) To secure an advantageous location in tapping the canal so that water can be readily conveyed from it to the highest point of the farm to be irrigated; (2) to take the necessary precautions to render the structure secure by cut-off walls and earth puddling and packing; and (3) to place the gate on such a level that it will draw its full supply when the canal is only partly full.

CULVERTS.—Various devices are used to conduct the flow of ditches across roads. A loose plank bridge or else a culvert formed of four planks of the requisite size and length are both quite common. So is the loose plank bridge. Unless lumber is cheap the short life of the former and the inconvenience of the latter render it worth while adopting a more durable structure. Perhaps the best substitute for lumber is the metal pipe and one of the most durable and easily installed pipes is the corrugated culvert pipe, Fig. 11, made of ingot iron. This is made in sizes ranging from 8 to 84 inches in diameter and two or more shipping lengths may be riveted together if necessary. In depressed crossings and wherever the pipe is under water pressure the seams of the pipe should be calked. The retail

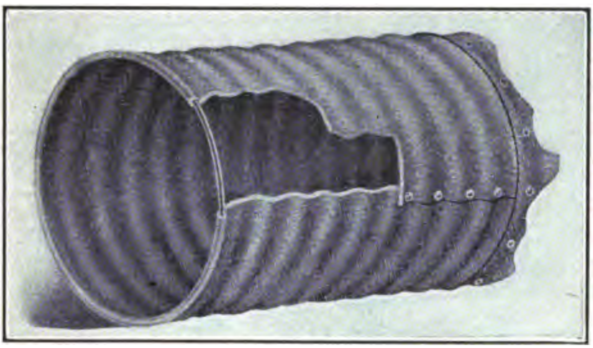

FIG. 11.—Corrugated pipe of ingot iron used for culverts.

prices range from 65 cents per foot for an 8-inch pipe to $1 and over for a 15-inch pipe.

WATER FOR DOMESTIC USES.—The settler under an irrigation enterprise has seldom an opportunity to obtain water from either springs or reservoirs for culinary and stock purposes. As a rule such supplies are obtained from the main canal or one of its distributaries or else from wells. Before canal water can be used for domestic purposes with safety to health it should be filtered. Filters are sometimes made by inserting a partition wall of porous brick within a cistern and allowing the canal water to filter through the wall. This practice is not to be recommended on account of the difficulty in cleaning or removing the

filter which soon becomes foul and clogged. A better plan is to filter the water in a separate vessel and conduct it from the filter to the cistern where only pure water is stored. The filter may consist of a concrete box with coarse gravel in the bottom and a depth of 15 inches of sand on top. A large oak barrel is a good substitute for the concrete box. In using a barrel a false bottom is inserted 2 or 3 inches above the true bottom and pierced with a number of holes which are covered with a brass wire screen. The filter consists of a thin layer of gravel, about 15 inches of sand and the same depth of water. The filtered water is conducted through a small pipe from the bottom of the

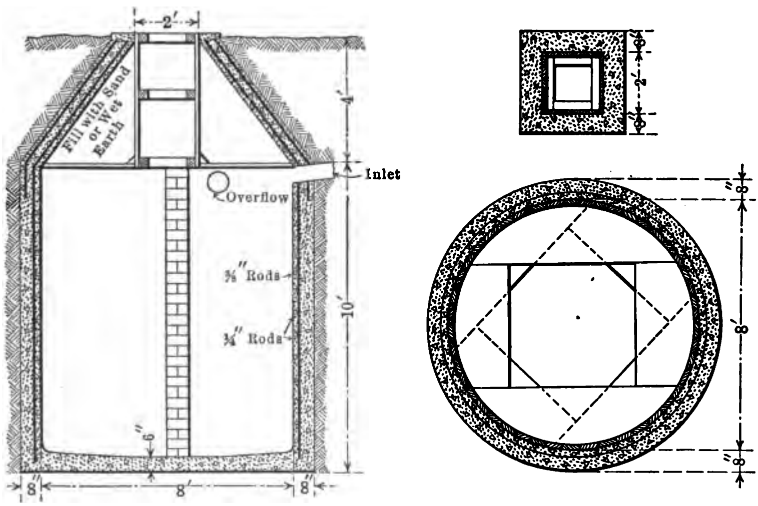

FIG. 12.—Concrete cistern for farm use.

barrel direct to the cistern. When the cistern is filled the sand should either be discarded or else exposed to the sun and air until again used.

The concrete cistern shown in Fig. 12[1] may serve as a model with the exception of the partition wall which is of doubtful utility. In constructing a cistern of this kind, make a circular excavation 16 inches wider than the desired diameter of the cistern and about 16 inches deeper than the desired depth. Make a cylindrical form as shown in the figure, the outside diam-

[1] Bul. 57, U. S. Dept. of Agri.

eter of which will be the inside diameter of the cistern. Mix the concrete in small batches fairly wet and tamp in between the form and the earth. To construct the conical portion build a floor across the top of the cylindrical form, leaving a hole of the desired size in the center. Brace the floor well with uprights from the cistern bottom. Build a cone-shaped mould of wet earth or sand and lay the concrete and reinforcing on this cone. Allow it to set and harden well before removing the forms and earth.

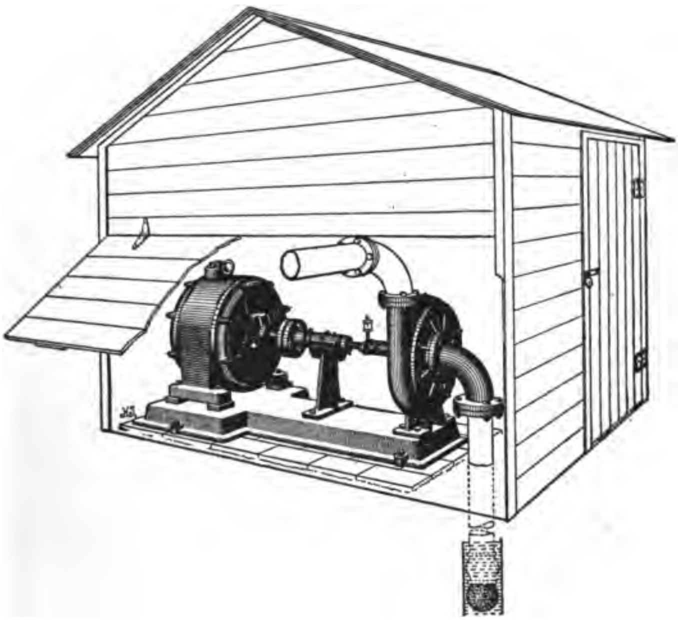

FIG. 13.—Small electrically driven pumping plant.

A large number of different types of wells are used throughout the arid region to secure potable water. The most suitable type to select depends to a great extent on local conditions and the practice followed in the neighborhood affords the best guide. One can usually secure the services of a contractor having the necessary equipment who will undertake to sink or bore a well at a certain price per foot.

Where it is desirable to combine water supply for domestic purposes with that of irrigation for a garden, lawn, shade trees,

or small orchard the water may be pumped from a canal, well, or other source by means of a windmill, gasoline engine or motor.

Where a small pumping plant is needed to furnish water for culinary and stock purposes as well as the irrigation of a garden and orchard the arrangement shown in Fig. 13 may be found suitable.[1]

A standpipe, tank, or reservoir is often a necessary part of small water supplies designed to serve a number of purposes. If the right elevation can be obtained a reinforced concrete stand-

FIG. 14.—Reservoir and pumping plant.

pipe forms an excellent part of a pumping plant since it can be designed in such a way as not only to store considerable water but to act as an equalizing and distributing reservoir.

In a flat country the pumped water is usually stored in an elevated tank. Concrete is too heavy for such a purpose but redwood stave pipe of large diameters may be substituted.

Where conditions are favorable, a reservoir should be substituted for the standpipe and tank on account of its cheap-

[1] The Use of Small Water Supplies for Irrigation by the author, Yearbook of U. S. D. A., 1907.

ness, durability and larger capacity. The reservoir and pumping plant shown in Fig. 14 while somewhat too large and costly for a farmer's use, may serve as a sort of model for a plant of small dimensions.

12. Pipes and Pipe Systems for the Farm.—The materials composing the pipes most commonly used by irrigators are concrete, clay, wood, and metal. A brief description of each of these kinds follows:

CONCRETE PIPE.—This kind of pipe is used quite generally in southern California for conveying irrigation water underground without pressure or under low heads not exceeding 10 to 15 feet. Mr. C. E. Tait, Irrigation Engineer of the Department of Agriculture, states that "a good pipe for the smaller sizes is made from a 1 to 3 mixture consisting of 5 parts cement, 6 parts sand and 9 parts gravel. A larger proportion of gravel may be used in the larger sizes. A good pipe may also be made of cement, sand and crushed rock, no particle being larger than one-half the thickness of the pipe."

TABLE No. 12

Size of pipe	Lineal feet per barrel of cement	Lineal feet per cu. yd. of gravel	Cost data per lineal foot				
			Cement	Gravel	Moulding	Coating	Total
4 in.	126–130	174	$0.023	$0.006	$0.020	$0.003	$0.052
6 in.	82–100	112	0.036	0.009	0.020	0.003	0.068
8 in.	64– 76	87	0.047	0.011	0.022	0.003	0.083
10 in.	48– 56	64	0.062	0.015	0.025	0.003	0.105
12 in.	36– 44	50	0.083	0.020	0.028	0.004	0.135
14 in.	28– 30	40	0.108	0.025	0.032	0.005	0.170
16 in.	26– 28	34	0.115	0.029	0.038	0.006	0.188
18 in.	22– 26	28	0.136	0.036	0.042	0.007	0.266
20 in.	18– 20	23	0.166	0.043	0.100	0.008	0.317
24 in.	12– 14	18	0.250	0.055	0.110	0.009	0.424
30 in.	8– 10	11	0.375	0.090	0.150	0.011	0.626
36 in.	6– 8	8	0.500	0.125	0.200	0.012	0.837

Failures in concrete pipe have been largely due to lean mixtures, the use of sand mixed with earth and improper moulding. A weak unreliable pipe is likely to result when the voids in the sand are not filled with cement, when earthy material is incorporated in the mixture or when the mixture is too dry when moulded. The porosity of concrete pipe is reduced and the carry-

ing capacity is increased by the application to the inner surface of a cement brush coating.

The prices for materials in 1914 in southern California were for cement delivered $3 per barrel, sand and gravel $1 per cubic yard, tampers $3 and mixers $2.25 per day of 9 hours. The quantities of materials used, their respective costs and the cost of the various processes in making pipe, exclusive of overhead charges and profits are given in Table 12.

MOULDING THE PIPE.—Concrete pipe as made in southern California for the farmer's use is moulded in 2-foot lengths with beveled lap joints. Since the price of moulds for pipe between 6 and 12 inches in diameter varies from $50 to $100 per set the tendency is to use the smallest possible number. This effort to economize frequently results in a brittle pipe caused by the use of too dry a mixture, such a mixture requiring less time in the moulds. To obviate this difficulty and increase the output from each set of moulds thin metal cylinders are sometimes introduced in the moulds and allowed to remain for some time around the freshly moulded pipe after its removal from the moulds. In this way a wetter mixture resulting in a stronger pipe can be made.

The making of concrete pipe is still in a formative stage. In recent years various methods have been designed and patented. Some of these will doubtless prove useless or impracticable but by combining the best features of several designs methods will become standardized in time.

Successful attempts have been made to lessen the arduous and slow process of hand tamping by placing the mould on a revolving table and operating the tamping-bar by machinery. The same end is perhaps better attained by subjecting the table to a succession of sudden and brief motions first in a horizontal and then in a vertical direction. These alternating jars serve to pack the material in a dense, uniform mass. This method is known as the Jagger system and seems to be especially well adapted to reinforced pipe.

Another method is to subject the freshly moulded pipe to the action of superheated steam which greatly hastens the setting of the concrete and permits the pipe to be withdrawn from the moulds without any serious delay.

In the manufacture of reinforced concrete pipe in Australia, to convey water for domestic, power, and irrigation purposes and for electric conduits, the packing is done by means of centrifugal force. The mould, which is 6 feet or more in length, is placed on journals in a horizontal position. Light reinforcing in the form of a cylinder is then inserted in the mould after which a wet concrete mixture is gradually poured in from each end. As the concrete enters the mould the latter revolves, at first slowly and later at a high rate of speed. The centrifugal force thus developed not only packs the concrete but forms a smooth finish on the inner surface of the pipe. The sections are true cylinders and reinforced collars are placed around abutting joints. This pipe is used under pressures of 75 pounds or more per square inch.

VITRIFIED CLAY PIPE.—Pipe made of moulded clay, kiln-burned and glazed is extensively used to conduct sewage in the sewer systems of towns and cities. The requirements for this service

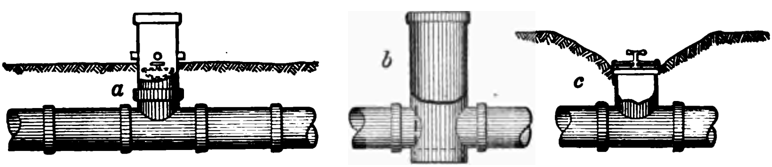

FIG. 15.—Fittings for vitrified clay pipe.

are quite rigid and the pipe which is rejected by the sewer inspector can frequently be purchased at a low figure. In this way the irrigator who resides within hauling distance of a town or city can usually obtain from the municipality or the clay pipe company a serviceable water pipe for low heads at reasonable prices.

In southern California the rejected sewer pipe is classified into three grades known as Nos. 1, 2, and 3 water pipe. The defects in No. 1 grade are not serious and can be depended on to stand a head of 20 to 30 feet in the smaller sizes and 15 to 20 feet in the larger sizes. The No. 2 grade consists of pipe which is cracked in the main part of the joint or length and withstands less pressure than No. 1. No. 3 grade is used only for drainage, being usually cheaper than the tile. The prices of grades 1 and

2 in 3-foot lengths, f.o.b. cars Los Angeles, are at this writing (1914) as follows:

TABLE NO. 13

Size	No. 1 Grade. Cents per ft.	No. 2 Grade. Cents per ft.
3 in.	4 7/8	4 1/8
4 in.	6 1/2	5 1/2
5 in.	8 1/8	6 7/8
6 in.	9 3/4	8 1/4
8 in.	12 3/8	10 1/8
10 in.	16 1/2	13 1/2
12 in.	20 5/8	16 7/8
14 in.	27 1/2	22 1/2
16 in.	34 3/8	28 1/8
18 in.	41 1/4	33 3/4
20 in.	56 7/8	48 1/8
22 in.	71 1/2	60 1/2
24 in.	81 1/4	68 3/4

Manufacturers of clay pipe furnish standpipes and other fittings similar to those furnished by the concrete pipe makers. The stand shown in Fig. 15a is used for orchard irrigation. A special fitting shown in Fig. 15b is also made for the insertion of a gate on a pipe line and a T joint with an "alfalfa" valve in position on the vertical branch as shown in Fig. 15c.

WOOD PIPE.—The various kinds of wood pipe used to convey water for irrigation purposes belong to one of two general types. One of these is the continuous stave pipe and the other the machine banded pipe. Since the former is only built in medium and large sizes in which the diameters run from 1 to 12 feet it is not well adapted to the farmer's needs and for that reason will not be considered here.

The factory for making machine-banded pipe in San Francisco, California, uses redwood; those located in Portland, Oregon, Tacoma and Seattle, Washington, and Vancouver, B. C., use fir. In the States of New York and Pennsylvania the pipes are made of white pine and tamarack while in Louisiana cypress is considered the most suitable wood.

A quarter of a century and less ago, machine-banded pipe consisted wholly of logs turned in a lathe, machine-bored and wrapped with flat steel bands. Staves 8 to 12 feet in length in the eastern factories and up to 20 feet in length in the western

factories have since been substituted for bored logs. The staves which vary in thickness from 1 to 1 3/4 inches are held together by galvanized steel wire spaced far apart or close according as the internal pressure of the water is low or high. In some factories flat bands of steel 14 to 16 gauge are used instead of the round wire. After the pipe is banded and the ends are milled for couplings each section is dipped in a bath of hot asphalt and when withdrawn is rolled in sawdust or shavings.

The joints are made in various ways. A common form for low pressures is that of the mortise and tenon joint. The joint

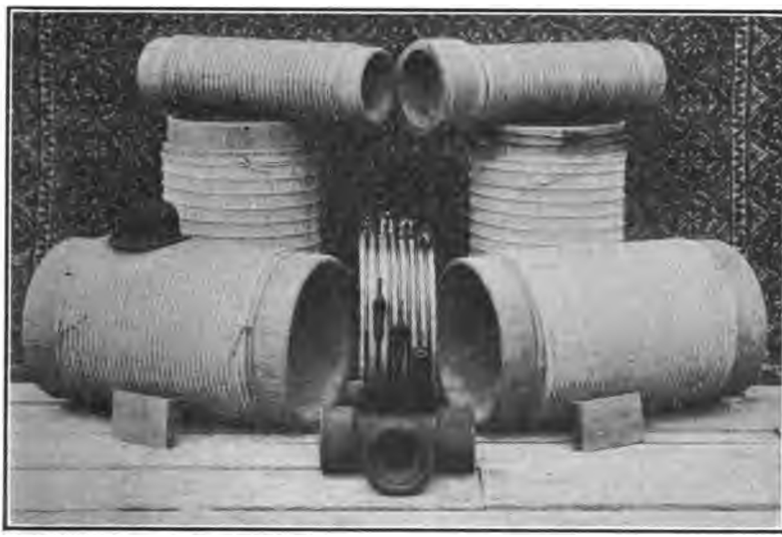

FIG. 16.—Forms of joints for wood pipe.

is reinforced when the pressure requires it. Sometimes tenons are made on both ends of each section and the coupling is made by means of collars. All three forms are shown in Fig. 16. In common with other kinds of pipes the joints in wood pipe are the chief source of trouble and expense.

According to S. O. Jayne, Irrigation Engineer, U. S. Department of Agriculture, the cost of laying wood pipe exclusive of earthwork, backfilling and haulage varies from 2 cents per lineal foot for pipes 4 to 6 inches in diameter up to 6 cents for pipes 24 inches in diameter.

The prices and weights per lineal foot of machine-banded pipe f.o.b. cars, Seattle, Washington, follows:

TABLE No. 14

Diameter	Head, feet	Price	Weight, pounds	Diameter	Head	Price	Weight, pounds
2 in.	50	0.087	3.1	10 in.	50	0.268	13.1
	100	0.09	3.2		100	0.347	14.7
	150	0.092	3.2		150	0.392	15.7
	200	0.10	3.4		200	0.455	17.3
	250	0.105	3.5		250	0.479	18.4
	300	0.116	3.6		300	0.503	19.4
4 in.	50	0.129	5.8	12 in.	50	0.322	16.8
	100	0.131	5.9		100	0.413	18.9
	150	0.134	6.0		150	0.450	19.8
	200	0.166	6.3		200	0.532	21.7
	250	0.176	7.0		250	0.618	23.8
	300	0.189	7.3		300	0.660	25.3
6 in.	50	0.163	8.3	14 in.	50	0.445	21.3
	100	0.168	8.9		100	0.550	23.0
	150	0.184	9.1		150	0.629	25.3
	200	0.226	9.6		200	0.745	28.2
	250	0.242	10.0		250	0.834	29.9
	300	0.258	10.4		300	0.916	32.3
8 in.	50	0.203	10.3	16 in.	50	0.547	24.7
	100	0.224	10.5		100	0.639	26.9
	150	0.292	12.8		150	0.734	29.3
	200	0.332	13.7		200	0.871	33.4
	250	0.366	15.6		250	0.987	36.2
	300	0.387	16.2		300	1.132	40.2

METAL PIPES.—Space will not permit even a brief description of each kind of metal pipe used by irrigators. References are made to the galvanized iron pipe in Art. 19 and to the corrugated pipe in Art. 11. Notwithstanding the large variety in the market by far the most common is the steel-riveted pipe. This pipe may be purchased in a large number of sizes ranging from 4 to 30 inches and over in diameter and capable of withstanding heads of 50 to 300 feet. Each joint of pipe is made of a single sheet of steel which is sized, punched, rolled and riveted. A number of these joints are then riveted together making a

shipping length of about 30 feet. Each length is immersed in a bath of hot asphalt before being stacked up in the shipping yards. For all sizes up to 12 inches designed for ordinary pressures the lengths are simply driven together, the smaller joint of one end telescoping the larger joint of the adjacent length. For high pressures and large sizes the circular seams are single riveted and the seams may be split-calked. For low heads, lighter and less expensive pipe of galvanized iron from 20 to 24 gauge, both coated and uncoated, has during the past few years come into somewhat extensive use throughout certain sections of the Northwest.

The following table gives the list prices of steel-riveted pipe in Los Angeles, California, in 1914, these prices being subject to a discount of about 15 per cent.

TABLE No. 15

Size	16-Gauge	14-Gauge	12-Gauge
4 in.	$0.19	$0.22	......
5 in.	0.23	0.27	......
6 in.	0.28	0.32	$0.41
7 in.	0.31	0.37	0.48
8 in.	0.34	0.40	0.52
9 in.	0.38	0.42	0.57
10 in.	0.41	0.47	0.62
11 in.	0.43	0.49	0.65
12 in.	0.46	0.55	0.69

PIPE SYSTEMS.—As irrigation practice develops the unlined ditch will gradually give place to pipes. Of late years more or less substitution of this kind has been made in western localities where water is scarce and costly and where large crop returns are secured. The same is true in the eastern part of the United States where water supplies are abundant and cheap. The eastern irrigator adopts the open ditch only as a last resort. He considers pipes the more efficient and economical for the following reasons. They are laid underground beneath the deepest furrow, there is practically no loss in conveyance, and time and labor are saved in applying the water. In the case of open ditches the western irrigator has to weigh their cheapness against a number of disadvantages. Among these may be mentioned the returns which might be derived from the valuable

ground occupied by open ditches, the damage done by noxious weeds which grow on their banks, the loss of water by absorption, the structures required to span them, the heavy maintenance charge, the inconvenience of crossing and recrossing them with teams and implements and the difficulty of distributing water from such channels.

The arrangement of pipe systems for irrigation is not unlike that for domestic water supplies in cities since the requirements

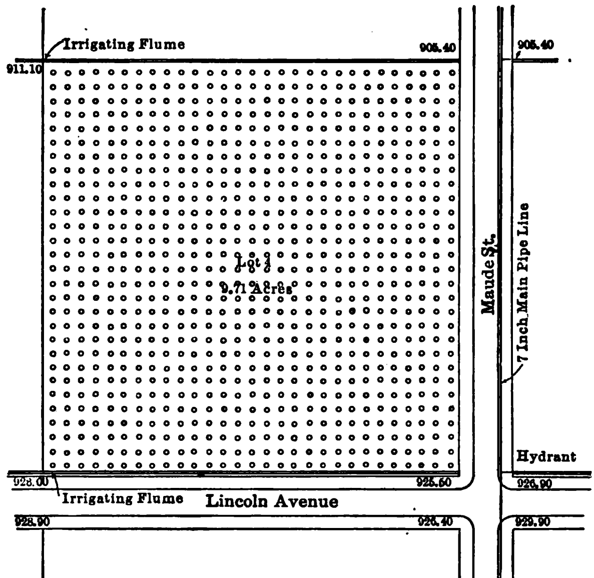

FIG. 17.—Orchard tract showing streets and pipe laterals.

are similar. There is usually the main conduit from which the feed pipes extend. The water carried by each feed pipe is distributed through lateral pipes which supply the various farms or fields. In cities water for domestic purposes is frequently metered out to each consumer. The same course has been followed by irrigation companies. A better and cheaper plan is to measure the water diverted into each distributing pipe and determine all water deliveries by the quantity carried in each and the number of hours it is used.

On the Gage Canal system in Riverside County, California,

the water supply for the tiers of 40-acre tracts is taken from the canal in riveted steel pipes varying from 6 to 10 inches in diameter. These larger mains are connected with 4-, 5-, and 6-inch lateral pipes of the same material, which convey the water to the highest point of each 10-acre tract. This general arrangement is shown in the sketch, Fig. 17.

Fig. 18 shows the plan of the pipe system of the irrigated farm of Granville W. Leeds at Rancocas, New Jersey, as designed and installed by Milo B. Williams, Irrigation Engineer of the Department of Agriculture. In this system a 24-horse-power gasoline engine (Gray), driving a No. 3 American 2-stage horizontal centrifugal pump raises water out of Rancocas Creek to a maximum height of 88 feet. A 5-inch galvanized steel pressure main conveys the water from the pump to a standpipe. From there the water is distributed through small overhead pipes to about 9 acres which are irrigated by the overhead spray method. Under a pressure of 30 pounds per square inch at the nozzles of the spray pipes the plant discharges from 265 to 300 gallons per minute.

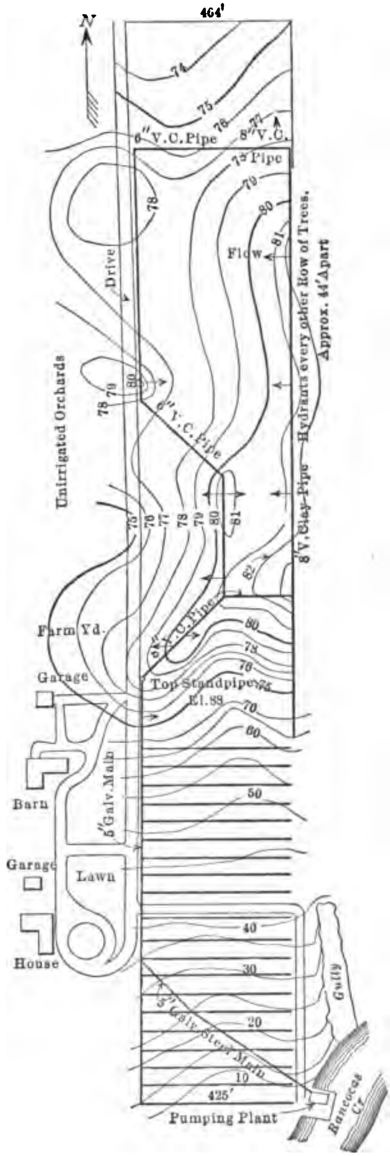

FIG. 18.—Plan of pipe system on an eastern truck farm.

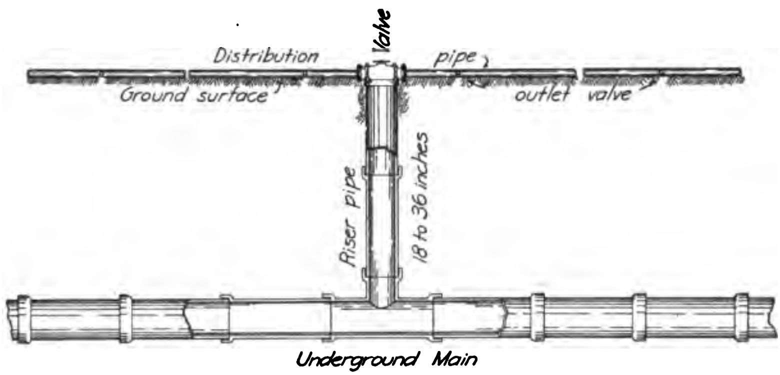

FIG. 19.—Underground pipe, hydrant, and distributor on an eastern truck farm.

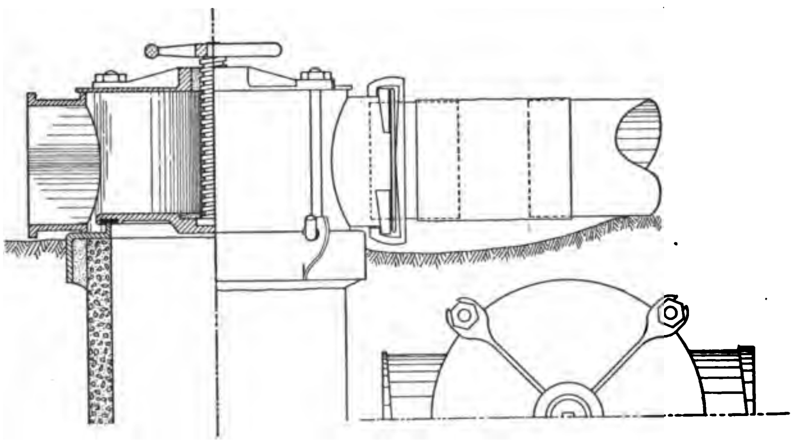

FIG. 20.—Details of hydrant shown in Fig. 19.

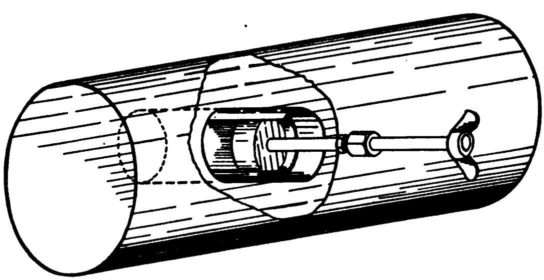

FIG. 21.—Detail of valve on distributor shown in Fig. 19.

Leading out from the centrally located standpipe is another line of low pressure pipe of 8-inch vitrified clay which is reduced farther on to 6-inch pipe. These pipes are laid beneath the surface so as not to interfere with plows or subsoilers and fit into the topography of the tract, Fig. 19. Hydrants or stands of the type shown in Fig. 20 are placed at the head of every other tree row or approximately 44 feet apart. A portable distributing pipe with openings spaced about 5 feet apart and controlled by special valves, Fig. 21, is attached by canvas hose to each hydrant in turn for the irrigation of each strip between the hydrants. The capacity of the plant when water is conveyed from the standpipe through vitrified pipe and distributed over the surface in furrow irrigation varies from 300 to 350 gallons per minute. The cost of this plant complete was $3440 or $123 per acre but the extra returns from the irrigated area in the way of larger and better crops has rendered it a highly profitable investment.

13. Pumping Plants. Source of Supply.—Only a relatively small part of pumped water is derived from surface supplies such as streams, lakes, reservoirs and canals. The utilization of these is comparatively easy since all that is required is a direct connection between the pump and the water by means of a suction pipe.

By far the greater part of the water raised by pumping plants is found at varying depths beneath the surface. The water so found does not move as in streams freely from place to place in more or less large volumes. It is divided up into an innumerable number of small particles which are enclosed for the time being within the interstices of earth and rock. Some of these materials are either so fine in texture or else so dense that they virtually imprison the water within their mass. Other substances are more open in texture and these permit the slow passage of water through their open spaces. Such formations are termed water-bearing strata which receive and give off water to the extent of 20 to 30 per cent. of their volume.

The percentage of open space in some material may exceed 40 per cent. When, however, the voids of coarse material such as gravel are filled with sand and those of the sand with silt or clay, the water-holding capacity of the material is greatly dimin-

ished and the amount of water which will pass through it in a given time is still further diminished. Whether the material composing a water-bearing stratum is of one kind or of several the amount of water which flows from it into a well, for example, is always less than the amount required for saturation. A certain percentage clings to each particle of silt, sand or gravel and can not be dislodged by the force exerted by gravity. As a result of tests conducted by V. M. Cone and the writer in 1907 the fine sandy loam of Fresno County, California, contained 30.5 per cent. of open space and gave off 22 per cent. after being saturated. A clay-sand loam of the same locality contained 40 per cent. of open space and gave off 25 per cent. In the coarser material penetrated by many wells the open space or porosity may be greater and such material may give off from a saturated mass fully 30 per cent. by volume of water. Under some conditions this underground water moves in a generally horizontal direction down a given slope at a slow rate of speed—often not more than a few feet per day. This is true of beds of streams which flow over porous material. When only a small part of this so-called underflow is withdrawn by pumps, the deficiency is speedily restored by the inflow. When, however, more water is withdrawn than the inflow can replenish the supply diminishes unless a low level is tapped.

Under other conditions there is little more than an up and down movement of the underground water caused by precipitation and floods on the one hand and deep percolation on the other. In such cases the withdrawal of water during an irrigation season usually lowers the water table but if this is restored when the pump ceases to run or at the close of the season or year no apprehension need be felt. It is only when the water table is permanently lowered as a result of pumping from season to season that a scanty or unreliable supply is indicated.

In calling attention to the longitudinal and vertical movements of underground water it is well to bear in mind that the water contained in any given water-bearing strata may be subjected to both movements in the same period of time.

According to the census there were in 1910, 15,803 pumping plants of all kinds in the United States. Out of this total

9297 were found in California and 1897 in the rice belt of the Gulf States. Since 78 per cent. of this kind of irrigation is confined to these two localities the information herein given concerning this subject will likewise be confined to these same localities.

WELLS.—According to C. E. Tait, the most common sizes of drilled wells for new plants in southern California at this writing (1914) are 12, 14, 16, and 20 inches in diameter. A few 24- and 26-inch wells are also in use. The increase in size in recent years has been largely due to two causes. The larger circumference of the casing permits more openings to be made and more water to enter from the adjacent gravel. They are also better suited to the use of deep well pumps of the plunger and turbine types in that they permit a long stroke at low speed.

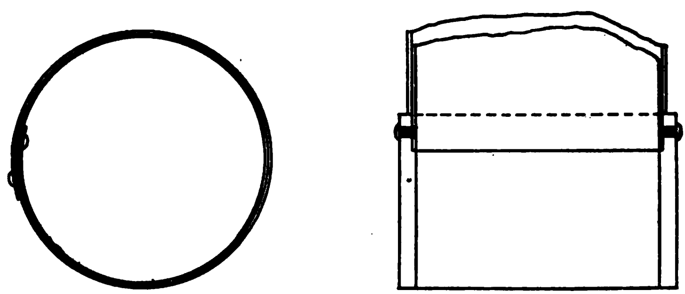

FIG. 22.—Well casing.

The casing consists of a double thickness of riveted steel sheets 2 feet long arranged as in Fig. 22[1] and broken jointed. The cost of casing per foot for various diameters and thickness of metal subject to a discount of 30 per cent. is as follows:

TABLE NO. 16

Diameter, inches	16-Gauge	14-Gauge	12-Gauge	10-Gauge
7	$0.59	$0.68	....	....
10	0.83	0.99	$1.20	....
12	0.90	1.06	1.37	$1.78
14	1.08	1.20	1.62	1.97
16	1.21	1.33	1.94	2.17
20	....	1.57	2.23	2.64
24	....	....	2.69	3.20

[1] Bul. 236, O. E. S., U. S. D. A.

What is known as a starter is a tube about 20 feet long riveted to the bottom of the casing. This consists of a triple thickness of metal for large wells and for wells in bowlders or rock. A steel shoe or ring is in turn riveted to the bottom of the starter. A 3-ply, 12-gauge starter for a 12-inch well costs $1.80 per foot, while a 12 × 3/4 inch ring costs $16.

Wells in southern California are drilled by contract. The equipment consists of a California portable rig costing $500 to $600 without the tools. In starting a well a hole is first bored and the starter inserted. A sand bucket is then used to make the excavation unless rock is encountered. The rig is provided with hydraulic jacks which apply a pressure of 100 tons or less to an iron ring which rests on the top of the casing. The cost of drilling in sand or clay exclusive of casing is $1.50 per foot for a 12-inch well. Contractors are usually protected by a provision inserted in the contract to the effect that if bowlders or rock are encountered requiring more than 2 hours to bore through an extra charge will be made.

Strainers, which form so essential a feature of many wells in the rice belt, are not necessary in southern California as there is no quicksand or very fine sand unmixed with coarser material. Water is admitted through long vertical slots in the casing which are cut by a special tool after the casing is in place. The cross sections of the openings thus made are trapezoidal in form, the narrowest side being at the outside to prevent clogging. Four vertical slots about 20 inches long are made in the circumference of each joint of a 12-inch casing opposite and slightly below each water-bearing stratum.

In the rice belt, according to C. G. Haskell, Irrigation Engineer, Department of Agriculture, the hydraulic rotary method for drilling wells is the most common. The equipment usually consists of a derrick 16 feet square at the bottom tapering to 4 feet square at the top and about 40 feet high. The first operation after the derrick has been built over the site is to sink a test hole by using a 4-inch pipe in order to get a log of the well. A fish-tail bit is screwed into the lower end of the pipe and its cutting blade makes an opening somewhat larger than the pipe as both are revolved. Muddy water is then pumped into the pipe and is discharged under high velocities through two 1-

inch openings in the bit at the lower end. The water carrying the borings then rises on the outside of the pipe to the surface. After the test hole has been drilled to the required depth the pipe is removed from the well.

The character of the materials, particularly those of the water-bearing strata are known from the log and suitable strainers and other equipment can then be ordered and transported to the site. The permanent well is then dug in very much the same manner as the test well.

PUMPS.—For low lifts not exceeding 30 feet, the horizontal centrifugal pump is perhaps the best type. Where there is little fluctuation in the water table and the lift is not over 25 feet they can be installed on the surface and belted or coupled direct to engines and motors. The same kind of pump can be lowered in a pit 10 to 15 feet below the surface in order to secure a safer suction and to adapt it to a somewhat higher lift.

For lifts between 20 and 75 feet the single-stage, vertical centrifugal pump is commonly installed. This kind of pump may be placed in the bottom of an open pit or shaft within safe suction reach of the water and if the water lift is stable it may be directly connected to an electric motor by vertical shafting.

Such installations are, however, rare in southern California on account of the seasonal and periodical fluctuation in the water table.

For lifts ranging between 75 and 150 feet the two-stage, vertical centrifugal pump is the most common. The limit of 150 feet or less is due largely to the cost of the shaft. These shafts or pits are 6 × 8 feet or 5 × 7 feet when curbed with redwood and circular when curbed with concrete. The cost of the excavation increases with the depth.

Owing to the expense of digging a pit and lining it with concrete, which though more expensive than redwood is in the end more economical, the tendency in late years has been to install turbine or turbine centrifugal pumps for all lifts over 100 feet and thus dispense with the open pit.

The Layne and Bowler Company manufactures a special form of centrifugal pump which operates within a steel casing. This steel casing is inserted by the rotary process previously described and may be lowered 50 feet or more below the water level. In

this way the pump is submerged. This type of pump is well adapted to conditions which prevail in the rice belt but is little used in southern California. There the orchardists prefer the double-acting, deep-well pumps with plungers operating within a cylinder of brass tubing and with a specially designed power head for converting the rotary motion of the belt pulley into the reciprocating motion of rods and plungers with quick return and lap stroke to prevent pulsations in the discharge of water. This type is used for lifts of from 150 to 400 feet.

For lifts between 300 and 400 feet the Pomona Manufacturing Co., Pomona, Cal., and the Deane Pump Works of Holyoke, Mass., make somewhat similar pumps to that just described but with three plungers. The lowest plunger is operated by a solid rod placed within a hollow rod which operates the middle plunger and this in turn is placed within a second hollow rod which operates the highest plunger. With three plungers the discharge of water is fairly constant and in consequence the power head for this so-called triplex deep-well pump does not require the quick return and lap in stroke which form so prominent a feature of the double-acting type.

Engines and Motors.—The power required to raise water for irrigation is now confined for the most part to gas-burning engines and electric motors. In localities far removed from oil wells, gasoline and, to some extent, distillate are the staple fuel products for such engines. A cheaper power can be produced by a new product of the oil wells known as "tops." In heating crude oil in tanks as a partial refining process for use in locomotives the top layer is removed and is now marketed as a special by-product. Its specific gravity ranges from 38 to 40 degrees Baumé, its flashing point is under 100 degrees and it costs 2 3/4 cents per gallon, f.o.b. Los Angeles. It is claimed that "tops" produces more power per gallon than distillate which sells for 8 and 9 cents a gallon.

For small and medium-sized plants up to 75 horsepower the most popular and cheapest at the present time in southern California is a gasoline engine so modified as to burn tops in its cylinder. A plant of this kind was recently installed by Raught Brothers, Redlands, California. It consists of a cased well 16 inches in diameter, a double-acting deep-well pump and a

60-horsepower gasoline engine. The plant discharges 75 to 80 miner's inches (673 to 718 gallons per minute) under a lift of 180 feet at a total cost, including fuel, attendance, interest and depreciation, of 0.0284 cent per foot acre-foot.[1]

Owing to the large output, the low first cost and keen competition, the price of electric current has been lowered in recent years. Electric current is now supplied to pumping plants between San Bernardino and Los Angeles at the rate of 1 cent per K. W. hour. As compared with oil-burning engines, induction motors have a somewhat higher efficiency and a lower cost for maintenance and operation. They are, moreover, adapted to a wider range of conditions and can be more readily operated.

When a 10-horsepower gasoline engine operates a centrifugal pump and raises a volume of water in a given time equivalent to the application of 5 horsepower, the efficiency of the plant is said to be as 1 is to 2, or 50 per cent. The efficiencies of pumping plants depend on a wide range of conditions and in consequence vary between wide limits. The experiments made by Le Conte and Tait in California nearly a decade ago revealed the fact that the efficiencies of many of the plants tested varied from 30 to 50 per cent. and that some of the poorest plants did not exceed 20 per cent. Improvements since made covering engines, pumps and installations have tended to increase efficiencies so that the range of the present time lies between 30 and 75 per cent. Other conditions being similar, the small plant operating under low lifts wastes the most power and farmers who install such should not figure on getting much more than 35 per cent. of useful work done.

[1] The expression *per foot acre-foot* means the raising of 1 acre-foot of water which is equal to 43,560 cubic feet, or 325,850 gallons, through a vertical elevation of 1 foot.

CHAPTER IV

METHODS OF PREPARING LAND AND APPLYING WATER

14. The Removal of Native Vegetation.—In arid America few places are so barren as not to produce plants of some kind, and the first step in preparing land for irrigation is the removal of this native vegetation. When this consists of native grasses, low cacti, or rabbit brush it can be plowed under or removed without much extra expense but when it consists of large sagebrush, greasewood, mesquite or other plants of shrubby growth the cost may be considerable. Still costlier is the removal of junipers, pines, or other trees—sometimes of considerable size—which grow in some of the less arid sections where irrigation is practised.

SAGEBRUSH.—Of all the desert plants, sagebrush is the most widely distributed. It covers thousands of square miles of the Rocky Mountain and Pacific Coast states and various methods have been employed in removing it from irrigable land.

Instances are recorded where sagebrush has been killed by irrigating the land heavily for a season. The wetting of the soil causes weeds and grass to grow and when these are dry they are set on fire and in burning the dead sagebrush is consumed at the same time. Such a practice, however, can not have a wide application, and where land and water are both valuable, it is not a practice to be recommended.

Sagebrush can be quite easily broken off at the surface of the ground, and in clearing large tracts, one of the most common practices is to break the brush by dragging a railroad rail over it, using a strong team at each end of the rail. The rail is dragged twice over, the second time in the opposite direction to the first. Sometimes if a rail is nòt available, a heavy stick of timber is used as a substitute, but with somewhat less satisfactory results. Though the rails are very commonly used straight, it is claimed they are more effective in tearing out and breaking off the brush if bent into a V shape. By using a rail in this way, nearly all

the sagebrush is broken off, and what little remains can be easily cut by hand with a mattock.

After railing, the sagebrush is either raked into windrows or piled by hand and burned. In districts where the soil is subject to blowing it is sometimes left in windrows 30 to 50 feet apart for a year or two to serve as a windbreak while the intervening space is placed under cultivation. The cost of clearing land by the method of railing varies with the density and size of the sagebrush but contract prices in the Northwest during recent years have ranged from about $2.50 to $3 per acre which includes burning the brush.

FIG. 23.—Twin Falls sage brush grubber.

Heavy two-bottom gang plows drawn by six large mules have been used with success in removing sagebrush in the Yakima Valley, Washington. This work was done by contract at $3 per acre. Five acres of plowing was an average day's work. In addition it cost $1.50 per acre to gather up and burn the brush; making the total cost of clearing and breaking $4.50.

In Colorado sagebrush has been plowed out with a gang plow and steam traction engine.

In southern Idaho, at a cost of $3.50 and up for clearing, plowing and leveling, sagebrush is cut by the "Twin Falls Grubber," Fig. 23. This implement consists of heavy steel knives suspended from and rigidly attached to a framework carried on two wheels. It can be so adjusted that the knives which are set in the form of a V with the point ahead can be lowered a few inches beneath the surface of the ground where it cuts off the roots of the sagebrush. This implement is not adapted to stony land.

Under certain conditions it is often more economical or satisfactory to remove the sagebrush by hand grubbing. For this work a sharp mattock is used and the brush is cut at the surface of the ground. This is most easily accomplished when the ground is frozen. Where the growth is of average size and density, one man can grub about 1 acre a day. To gather up and burn the brush will require possibly half a day more, making the cost of clearing by hand, with wages at $2.50 per day about $3.75 per acre.

GREASEWOOD.—This is another shrubby plant having a wide range of distribution from the upper Missouri River region south to Mexico, and west to the Sierra Nevadas and Cascade Mountains. Its presence on the plains is not so general as sagebrush. It is often found and seems to thrive best on soils more or less impregnated with alkali and its presence for this reason is usually looked upon with suspicion. A height of 8 feet or more is sometimes attained by this plant.

MESQUITE.—Mesquite is found in the far Southwest from central Texas to eastern California. According to its surroundings it varies from straggling spiny shrubs to a widely branched tree 50 feet high and 3 feet in diameter. The latter size is attained only in the rich valleys having an abundance of moisture. On the arid plains, as a shrub only 2 or 3 feet high, the roots may extend to water at a distance of 60 feet or more. (Bergen and Davis, Principles of Botany, p. 27.) Greasewood and mesquite such as is usually found on lands suitable for irrigation can be cleared by the same methods commonly employed in the removal of sagebrush.

Large trees are not commonly found in regions where land is prepared for irrigation, but in some localities, junipers, pines or

other trees of considerable size have to be removed. As a rule, all trees large enough for wood or saw timber are removed first, then the smaller trees are slashed, and when dry, burned together with the tops of the larger trees. Small pine stumps rot quickly, and within a year or two after the cutting those 4 to 6 inches in diameter may often be removed by a direct pull with a good team. For stumps of larger size, some one of the many types of stump pullers is employed and more or less dynamite and stump powder

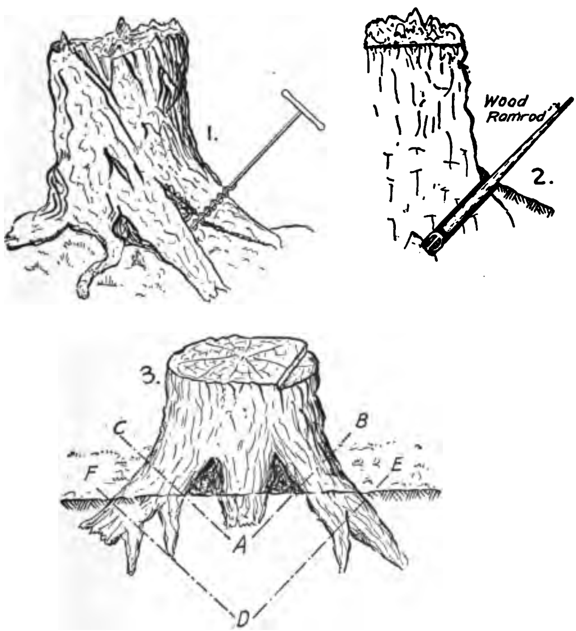

FIG. 24.—Blasting stumps.

are used to split or blow out the ones too big to be handled readily with the pullers. The cost of removing trees and stumps varies widely according to the kind of trees and the number to the acre. In clearing several thousand acres of pine land from which the saw timber and wood has largely been removed, in the vicinity of Spokane, Washington, the cost ranges from $25 to $60 per acre. The Hercules stump puller is used mainly, and this is supplemented by powder. In parts of British Columbia, where land is cleared for irrigation without making any use of the wood

or saw timber, the cost per acre for removing trees and stumps runs from $75 to $150 per acre.[1] The tools used in blasting, the manner of tamping the charge and the best location for the charge are shown in Fig. 24 taken from Bull. 134 of the Minnesota Agri. Exp. Sta.

15. Preparing the Surface for Irrigation.—Following the removal of native vegetation land to be irrigated usually requires grading, or smoothing in order that water may be distributed or spread over it uniformly with a minimun of labor and expense. In some parts of the West large areas of land are found which are naturally smooth, and consequently require very little grading preparatory to irrigating, while in other sections the natural topography of the land is so irregular that the work involves a heavy expense. There is frequently wide variation also in the requirements of different tracts in the same locality. By leveling or grading is not meant the reduction of the land to a level surface as this would in most places be not only impracticable but undesirable. Except where the land is very flat, grading as a rule involves only the removal of knolls and hummocks which interfere with the flow or spreading of the water, and the filling of depressions into which the water would collect to a detrimental extent. The aim in grading should be to obtain plane surfaces. These, however, may have little or much slope according to the local conditions found.

S. O. Jayne, in charge of the Irrigation Investigations of the Department of Agriculture in the State of Washington, states: "In no instance should the importance of securing a smooth surface be underestimated. Very often the saving of the few dollars needed to properly finish the grading of a tract of land may mean an annual loss of many dollars worth of time, water and crops due to the difficulty of irrigation. Frequently the apparent smoothness of a piece of land may lead to the belief that no grading is necessary. It is not often however that a natural surface is found that can not be improved to some extent. Sometimes, in the rush of development work, orchards or other crops are planted before sufficient grading is done, with

[1] For cost of clearing land in western Washington, see Eng. and Contracting magazine, Vol. XXXVI, pp. 252, 273, 313, 451, also Wash. State Exp. Sta. Bul. No. 101, also U. S. D. A., B. P. I., Cir. No. 25.

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the idea that the surface is good enough or that this important matter can be deferred until some more convenient time. A greater mistake than this is seldom made in connection with irrigation farming."

If the soil is fairly uniform for a considerable depth, as it is in many arid districts considerable of the surface layer may be removed without permanently impairing the productivity of the land. But if coarse gravel or some other form of unproductive subsoil occurs within a foot or two of the surface, a compromise must be made between the advantages of good grading and the disadvantages of poor soil. Under such conditions, it may sometimes be practicable, in a limited way, to move the surface soil to one side, remove so much of the poor subsoil as required and then replace the surface soil. It may be easier and better to modify the usual method of irrigation to suit the land, than to modify the land to suit the usual method of applying water. Grading is frequently carried too far on

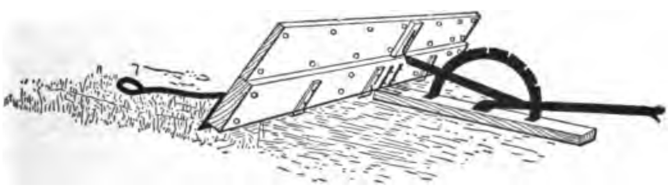

FIG. 25.—Buck-scraper.

this kind of soil but even under the most unfavorable conditions some improvement of the surface is usually possible.

The cost of preparing the surface after clearing runs all the way from a few cents to $50 or more per acre, depending mainly on how much dirt has to be moved. If the land has not been broken up in removing the native vegetation, the first plowing, which as a rule can be done with an ordinary strong plow and three or four horses, will cost from $2 to $2.50. This, however, is about as far as any itemizing of cost can be carried. In some parts of the West where land is held at $150 to $300 per acre, a cost of from $15 to $30 per acre for grading is not unusual, nor is it considered excessive. This, however, is higher than the average cost of such work.

If it is necessary to move much earth and the haul is short,

one of the best implements for the purpose is the buck-scraper, Fig. 25. In its simplest form it consists of a 2-inch plank with a steel shoe on the cutting edge and a tail board for holding the plank in position while filling, and for controlling the angle of it while spreading the dirt. Scrapers of this type have been made in lengths up to 24 feet but the size commonly used for four horses is 8 feet long and 2 feet wide. The 4-horse size is securely ironed and bolted together and can be made by the local blacksmith or on the farm at a cost of about $14. Some scrapers have a lever attached to the tailboard so that the scraper can be set at the desired angle in loading or spreading.

In parts of California a modified buckscraper or planer has been found especially useful on a slightly uneven ground. This consists of a base made of 4 × 12 inch plank 14 feet long and a

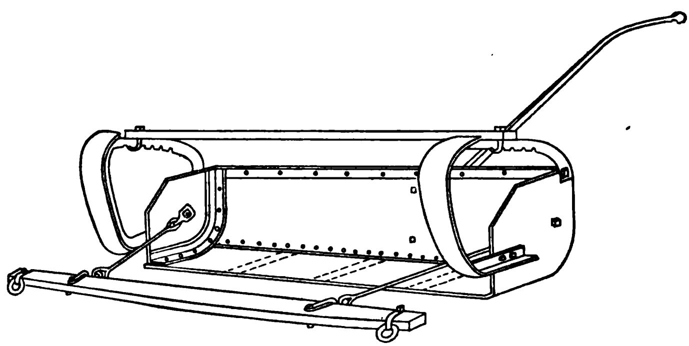

Fig. 26.—Fresno scraper.

back 2 inches thick, 18 inches high and 12 feet long. The base and back are held together by the extension of the steel plate with which the cutting edge and bottom of the base plane are shod and by iron straps on the front side of the upright plank. Foot boards are bolted across the base plank which extends a foot beyond the back at each end. Four mules are used at each end of the planer, the hitch being made to the base plank below the footboards. The drivers regulate the action of the implement by shifting their positions forward or backward on the footboards.

If the grading is heavy and the haul long, the "Fresno" scraper, Fig. 26, is the most satisfactory implement. This is a steel scraper 4 to 8 feet long which works on the same prin-

ciple as an ordinary "slip." A single steel handle about 4 feet long, attached at the middle of the back of the scraper serves both as a means of regulating the dip in loading, and of dumping and spreading the load. Usually a short piece of rope is attached to the end of the handle to facilitate turning the scraper back into position preparatory to loading. The common sized "Fresno" is pulled by four horses, but a smaller size suitable for two horses is also made.

The scrapers so far described are used for rapid movement of earth, and are not especially adapted to the work of making a finished surface. This is done with some form of rectangular leveler, the function of which is analogous to that of the long "jointer" plane used by a carpenter to smooth the edge of a board after the prominent humps have been removed with a short "jackplane." These levelers are made in many sizes and proportions to suit the local requirements, but the principle of their use is for all the same. The leveler is intended to remove the minor irregularities of the surface by spreading the earth left in bunches by the scraper, and by filling the slight depressions which ordinarily can not be detected with the eye. After having been properly leveled with a leveler the field should present a smooth plane surface.

The rectangular float[1] or "box leveler," Fig. 27, generally used is essentially a frame about 6 feet wide and 14 to 24 feet long, made of 2 × 8 inch or 2 × 10 inch planks set on edge; several crosspieces being used in addition to the ones at the ends. The framework should be diagonally braced on top, and well spiked or bolted together. The crosspieces should be faced on the front side with steel or iron plates. A footboard placed on top, in the middle, parallel to the long side affords a place for the driver to stand. The hitch is made so that the leveler is drawn lengthwise and the action of the leveler can be regulated to some extent by the driver shifting his position forward or back. The number of horses required varies with the size and weight of the implement. Four to six are commonly used, but more are sometimes put on very large levelers. In the Imperial Valley, California, rectangular levelers have been made in sizes up to 12 × 30 feet, requiring 16 horses and an operator in addition to the

[1] Farmer's Bulletin No. 392, p. 17.

driver. A rectangular leveler suitable for use with two to four horses is a very inexpensive implement that can be made on the farm, and it will often be of value in smoothing plowed fields in years succeeding the original grading.

Graders or levelers of other types are used in some localities. Some of these are patented machines. These cost more, and farmers generally prefer the less expensive home-made ones which are very satisfactory.

When preparing the surface for irrigation, sufficient soil to allow for settling should be placed in depressions of any considerable size, and before the field is seeded to permanent meadow or other long term crops, it is well to first irrigate it thoroughly.

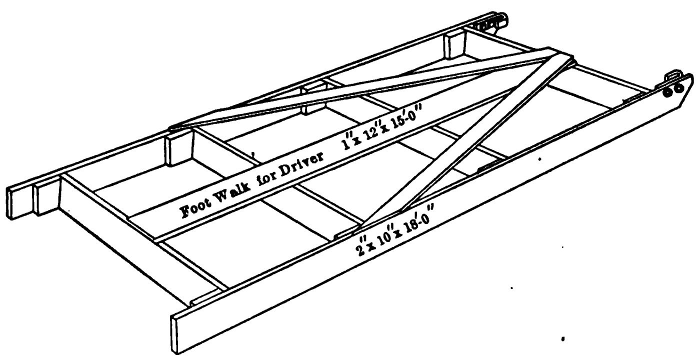

FIG. 27.—Rectangular float or box leveller.

The application of water will settle the soil of fills, and disclose any need of further grading more or less of which is usually required to put the surface in perfect shape.

16. Furrow Method of Irrigation.—As a rule the furrow method is used to irrigate orchards, small fruits, root crops and vegetables. It is adapted to a wide variety of soils and surface slopes. Porous soils and flat slopes, however, should be watered, if possible, in some other way on account of the loss of water by deep percolation in the former and the sluggish movement of the small streams in the latter. The essential features of furrow irrigation are the head ditch, flume or pipe from which the water is distributed, and the furrows. The earth head ditch is still common but making openings in its lower bank with a shovel

is being replaced by the use of the more stable and permanent openings.

EARTHEN HEAD DITCHES.—A skilled irrigator may adjust the size and depths of the openings in a ditch bank so as to secure a fairly uniform flow, but constant attention is required in order to maintain it. If the water is permitted to flow for half an hour unattended the distribution is likely to become unequal. The banks of the ditch absorb water and become soft and as the water rushes through the openings, erosion enlarges them, permitting larger discharges and lowering the general level of the water in the ditch so that other openings may have little or no

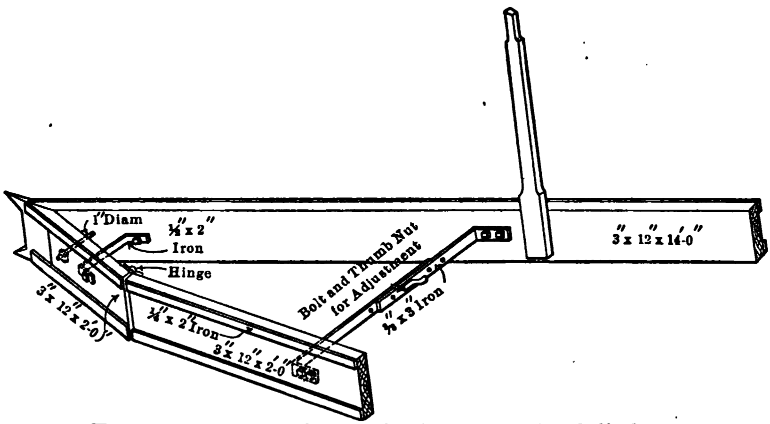

FIG. 28.—Home-made crowder for making head ditches.

discharge. Even if it were possible to divide the flow of the ditch equally between a certain number of furrows the difficulty would not be overcome, because the number of divisions would invariably be too small. In using such crude methods it is difficult to divide a stream of, say 40 miner's inches into more than about ten equal parts; but good practice frequently calls for a flow in each furrow of from one-fifth to three-fourths of a miner's inch, which can not be secured by this method.

One of the most serviceable home-made implements for making head ditches is the crowder of which several forms are shown in Figs. 5 and 28.

HEAD FLUMES.—In the Northwest where durable lumber can be purchased at reasonable rates, timber flumes are often used

to distribute water to furrows. When installed for this purpose they should be but slightly elevated above the surface of the ground to prevent soil erosion and the scattering of the stream

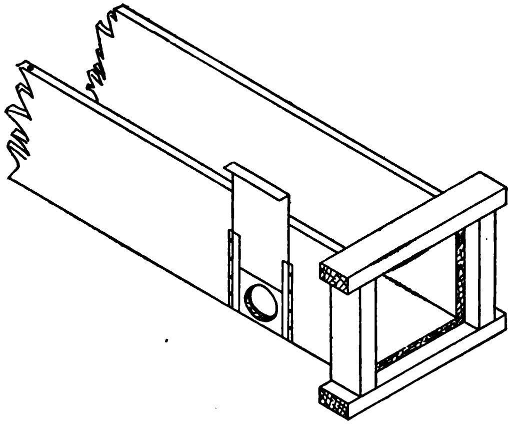

FIG. 29.—Common form of wooden head flume.

by strong winds. Flumes 6 × 6 inches and 8 × 8 inches are the most common. The sides are of 1-inch lumber but the bottoms are frequently 1 1/4 or 1 1/2 inches in thickness. The lumber, preferably cedar, is purchased in lengths of 16 to 18 feet. Collars made of 2 × 4 inch fir joists for the bottom and sides and 1 × 4 inches for the tops are placed around the flume at each joint and midway between joints. The water is distributed to the furrows through holes the flow to each being regulated by a metal slide in the manner shown in Fig. 29.

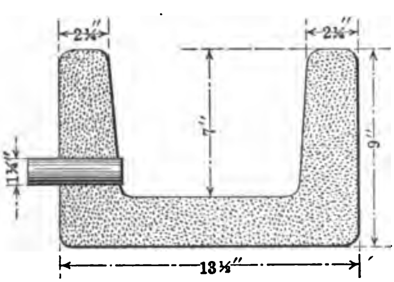

FIG. 30.—Concrete head flume with opening.

Where suitable lumber may be had for $15 per M. the cost of head flumes in place of the kind described varies from $4.50 to $6 per 100 feet of length.

In parts of the West where lumber is costly head flumes were formerly built of cement but these in turn are giving place to

concrete pipes. By means of a specially designed machine, which is patented, cement mortar composed of one part cement to about six parts of coarse sand is fed into a hopper and forced by lever pressure into a set of guide plates of the form of the flume. Such flumes are made in place in one continuous line across the upper margin of the orchard tract. After the flume is built but before the mortar has become hard, small tubes from 3/4 to 1 1/2 inches in diameter, the size depending somewhat on the size of the flume, are inserted in the side next the orchard (Fig. 30). The flow through these tubes is regulated by zinc slides. Flumes of this kind are made in five sizes, the smallest being 6 inches on the bottom in the clear and the largest 14 inches.

At a slightly greater cost a stronger flume can be built by the use of moulds. The increased strength is derived from a change

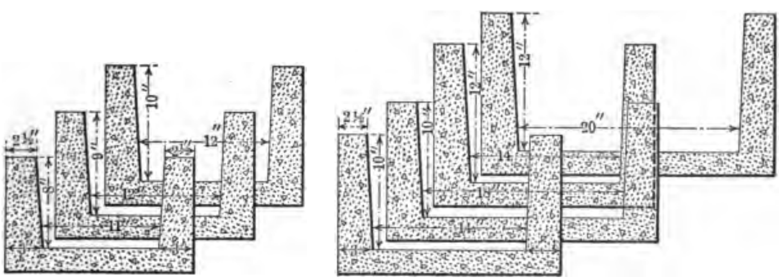

FIG. 31.—Types of concrete head flumes.

in the mixture. In the machine-made flume, the mixture of one part cement to five or six parts of sand is lacking in strength, for the reason that there is not enough cement to fill all the open spaces in the sand. In using moulds, medium-sized gravel can be added to the sand and the mixture resembles that of a common rich concrete (Fig. 31).

PIPES AND STANDS.—Head flumes, being placed on the surface of the ground interfere with the free passage of teams in cultivating, irrigating, and harvesting the crop. Dead leaves from shade and fruit trees also clog the small openings in the flumes. These and other objections to flumes have induced many fruit growers of southern California to convey the water in underground pipes and distribute it through standpipes placed at the

head of the rows of trees. Both cement and clay pipes are used for this purpose.

This method of distributing water to orchards is described by C. E. Tait in O. E. S. Bulletin 236 from which the following illustrations are taken. Fig. 32 shows a concrete head pipe 8 inches in diameter laid with its top 12 inches below the surface of the ground. The cut likewise shows the larger stand with its valve through which the water is admitted to the head pipe and the smaller distributing stand with its valve through which the water flows to the furrows. The methods used in laying concrete pipe and in placing stands are still further illustrated in Plate II.

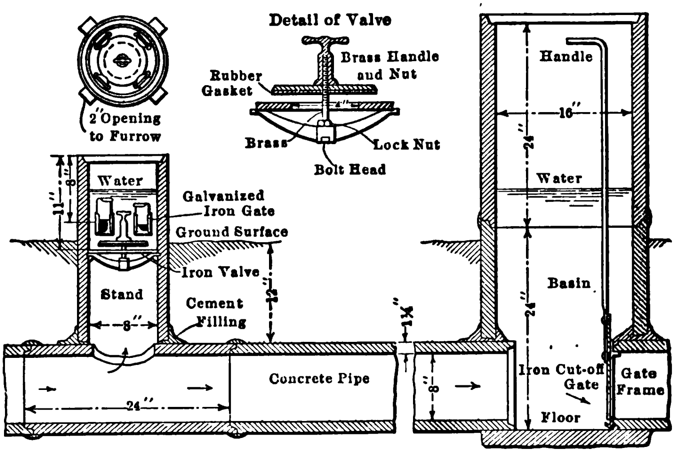

FIG. 32.—Concrete head pipe, with stands, valves, etc.

FURROWS.—The depth, spacing and length of furrows depend on a variety of conditions pertaining to crops, soils, and climate. In growing shallow-rooted crops or in irrigating a shallow soil, the furrow should likewise be shallow or of medium depth in order to moisten the soil around the roots and lessen the loss by deep percolation. However, in growing such crops, it is well to bear in mind that a large part of the upper 12 inches of soil in an arid climate can not be utilized for the nourishment of plants for the reason that the heavy evaporation robs it of its available moisture.

In all cultivated crops the grower should figure on reserving

FIG. A.—Laying concrete pipe.

FIG. B.—Setting stands.

(*Facing page* 76.)

a certain depth of the top soil to be used as a sort of blanket or dry soil mulch covering to protect the moist soil beneath. It is unfortunate that the soil so reserved is the most fertile, the best aerated, and the most easily worked soil of the field. In the experiments conducted by Dr. Loughridge of the University of California and the writer in 1905 in the citrus orchards of Riverside, California, it was shown that irrigation by means of a large number of shallow furrows followed by shallow cultivation was not good practice for that particular product, soil and climate. During the dry hot months of summer little free moisture was found in the upper 12 inches of soil prior to the time of irrigating. In other words the moisture content of the top foot of soil was wholly inadequate to support plant life. As a result the tree roots found in this layer of soil were either withered or unable

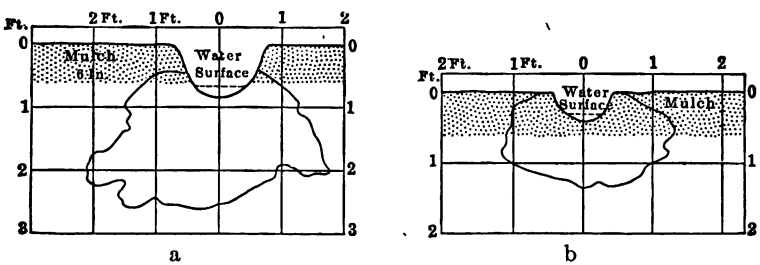

FIG. 33.—(a) Distribution of water from deep furrow. (b) From shallow furrow, in same time.

to perform their proper function. Orchardists who permitted the roots of trees to be lured near the surface during the winter rains were disappointed in learning that the trees after expending a part of their vital force in developing roots to occupy this new feeding zone were damaged by the subsequent withering or inaction of part of the root system so formed. Modern practice in orchard irrigation in southern California aims to prevent by frequent and deep cultivation the formation of roots near the surface. This results, as has been stated, in setting aside the top layer of soil in order to conserve and make more constant the moisture content of the remainder. The depth of this top layer varies with different conditions. A depth which would suffice for the low temperature and light evaporation of the Bitterroot Valley, Montana, might have to be increased 100 per cent. in

Santa Ana Valley, California or the Salt River Valley in Arizona. The same principles however, apply to all three localities.

From the foregoing it is observed that the top layer of dry soil mulch should not be irrigated. This can be accomplished in part at least by the use of deep furrows. Fig. 33a shows the distribution of the water in 7 hours from a furrow 10 inches deep and Fig. 33b a similar distribution from a furrow 5 inches deep in the same time. From the former it will be seen that little of the mulch is moistened and that the water has a wide distribution at a depth of 2 feet below the surface where the most roots

FIG. 34.—Orchard irrigation showing deep furrows.

are to be found, whereas in the latter nearly one-half of the water applied has found its way into the soil mulch to be speedily dissipated by evaporation. According to the present practice in citrus irrigation, four to six furrows are made between the rows in the heavier soils and two to four in the lighter soils. These furrows are made 8 to 9 inches deep and are made by attaching lister plows to the frames of wheeled cultivators. Such furrows are shown in Fig. 34.

LENGTH AND LOCATION OF FURROWS.—In porous soils it is often found necessary to limit the length of furrows to 200 feet. Even

in reasonably tight soils it is seldom wise to exceed a length of 660 feet. These limitations as to length are made for the purpose of securing a more even distribution of the water. The main defects of a long furrow one-eighth to one-quarter of a mile in length are the over-irrigation of the subsoil near the head ditch or flume if the soil is porous and the flooding of the lower portion of the field if the soil is impervious. A good arrangement in medium soils is to divide a 40-acre tract into three belts by as many head ditches, thus making the furrows in each belt or field 440 feet long.

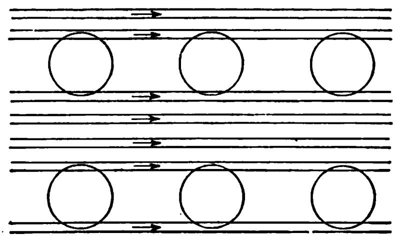

Fig. 35.—Furrow irrigation showing dry spaces.

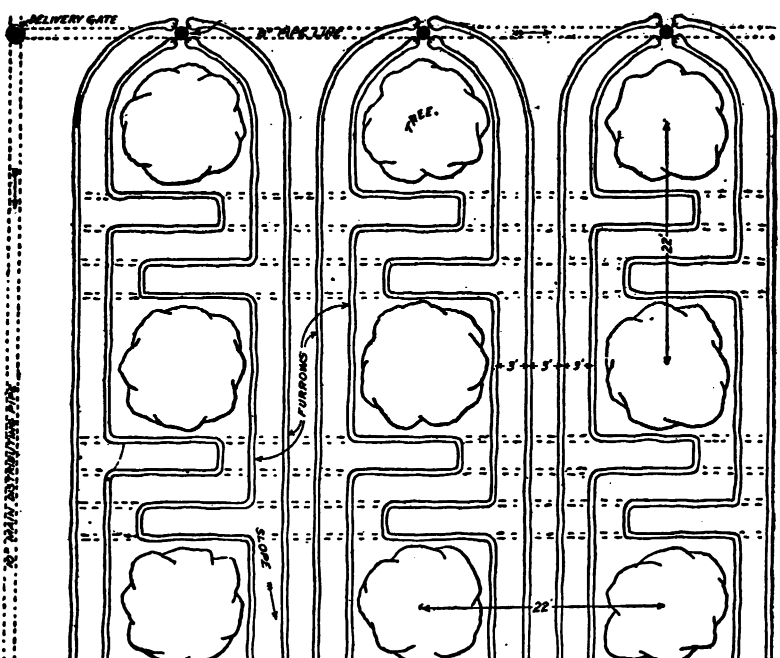

Fig. 36.—Plan for laying out zigzag furrows.

In irrigating small fruits, roots, vegetables, and to some extent orchards by the furrow method, the furrows are made parallel to the rows. In the case of mature orchards, however, cross-furrowing is gaining in popular favor. The purpose of this modification is to moisten the dry spaces shown in Fig. 35. Each space in mature orchards may contain from 100 to 150 square feet which usually becomes so dry that it is worthless as a feeding ground for roots. In order to moisten these dry spots, first, cross-furrows, indicated by the dotted lines in Fig. 36, are made, then the regular furrows are made after which the zigzag system as shown is completed by a little hand work with a shovel. Since the flow in each furrow can be quite accurately gauged by the slide on the stand, it is customary to turn in more water to the furrows which feed the cross furrows.

Cross furrowing is sometimes resorted to on steep slopes to lessen the velocity of the water and thus prevent erosion. It is also made use of on the lower portions of orchard tracts to secure as deep a penetration of moisture as occurs from the direct furrows on the upper portions. On very steep slopes, the rows of orchard trees are planted on grade lines, the fall being 3 to 4 inches per 100 feet in ordinary soils. In such cases the furrows are made parallel to and on the same grade as the tree rows.

17. Corrugation Method of Irrigation.—This is a modified form of furrow irrigation and is quite extensively practised in the states of Idaho and Washington. It is adapted to a rather wide range of topography, soils and crops, but the most favorable conditions for its use are a rather steep slope and medium soils as regards sand and clay. The reasons for these requirements are readily explained. Considerable slope to the field is necessary in order to create motion in the small quantity of water which flows in each corrugation. Again, in coarse porous soils there is too heavy a loss due to deep percolation and in heavy clay soils too many corrugations and too much time are needed in order to moisten the entire top layer of soil.

HEAD DITCHES.—For average fields of about 10 acres in extent the head ditch is made about 2 feet wide at the water line. A light grade with a correspondingly low velocity is preferable in order to check and control the flow with greater ease. A grade ranging from 0.05 to 0.25 per cent. may be used, but about 0.15 per

cent. is ideal for average soils. After the grade stakes are set a dead furrow is plowed along the line. This can be cleaned out with the ordinary "A" ditcher after which one or more furrows is plowed along the bottom throwing the dirt down hill. The "A" ditcher is again run through twice. With the exception of a little hand work the head ditch is then completed.

CORRUGATIONS.—The size of the corrugations depends on the character of the soil, kind of crop, and length of run. In sandy soils liable to cave in or erode the corrugations are made larger than in clay soils. In perennial crops such as alfalfa or clover they are also made larger than for annual crops since the cutting and harvesting of hay crops tend to fill up the corrugations. As regards the length of the run it is never advisable to exceed one-eighth of a mile (660 feet). An excellent arrangement under normal conditions is to divide a 40-acre field into three runs of 440 feet each.

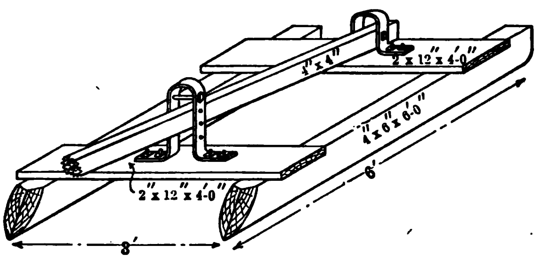

FIG. 37.—Furrower designed by Don H. Bark.

The distance between the corrugations is determined by the texture of the soil and the action of capillarity in conducting moisture from wet to dry soils. When this action, which is called "subbing" by the irrigator, is unimpeded the distance may be as great as 4 feet or more but in the more impervious soils it is frequently 18 inches or less. The spacing of the corrugations in southern Idaho is 2 1/2 to 3 feet. A safe rule to follow is to space the corrugations so that a small stream running in each for 12 to 24 hours will moisten all the intervening soil.

The best field slope for this method of irrigation is a fall of 1 foot in every hundred feet but by decreasing the flow so as to avoid erosion slopes as steep as 15 to 20 feet per hundred feet may be successfully watered. Fields are corrugated or furrowed

after seeding but before the seed has sprouted. An implement resembling the front runner of a bob sled, Fig. 37, designed by Don H. Bark is now much used for this purpose in both Wyoming and Idaho.

HEAD DITCH DISTRIBUTARIES.—Small tubes 16 to 24 inches in length made of four pieces of lath inserted in the lower bank of the head ditch serve to regulate the flow in each corrugation. All tubes between checks are puddled in at the same level and at the same distance below the water line so as to equalize the discharge through each. Small metal tubes are also used for the same purpose but they are more expensive and wash out more readily. Others use small syphons of rubber hose or pipe which

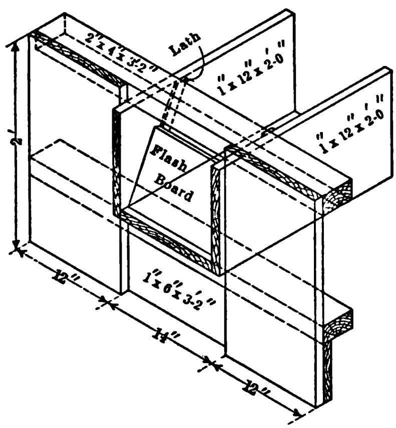

FIG. 38.—Check box for corrugation method of irrigation.

are transferred from place to place as needed but the trouble met with in setting each syphon is a serious objection to this device. At other times diversions are made from a small temporary and supplemental ditch extending for 100 feet or so parallel to the main head ditch.

CHECKS.—The surface of the water in the head ditch is held from 1 to 2 inches above the top of the spouts by means of checks. These are spaced at long or short intervals depending on the grade of the ditch and the kind of check used. When canvas dams are inserted they are placed far enough apart so that there will be a fall of about 6 inches between every two.

If wooden checks (Fig. 38) are used the fall may be 6 to 10 inches.

Head of Water.—The most suitable head of water for this method of irrigation varies from 1 to 2 second-feet. Each second-foot is distributed among 40 to 120 corrugations, the largest number being used on the steeper grades.

18. Flooding Methods of Irrigation.—It is impossible to state with any degree of certainty which method of flooding was first put into practice but it may readily be assumed that the "wild" or "mountain" method was one of the earliest methods due, no doubt, to the low initial cost of putting water upon the land. Under this method practically the entire cost of preparing the land for irrigation is expended in the building of laterals and but little money is spent in leveling or preparing the land.

The laterals may be located in one of three ways, namely: (1) On contours, (2) down the steepest slope, or (3) diagonally down the slope.

1. The laterals are built approximately along contours and are given just enough slope to produce the desired velocity of flow. Irrigation is accomplished by turning the water out at intervals along the lateral and allowing it to flow down the slope to the next lower lateral. This method is usually employed on very steep slopes.

2. Laterals are built directly down the slope, the grade of the lateral approximating that of the slope, and usually no attempt is made to reduce the velocity of the water. The water is turned out at intervals along the lateral and the flooding is accomplished by the water flowing simultaneously laterally and down the slope. This method can not be employed on very steep slopes as the water will have a tendency to follow alongside the lateral and produce serious washing of the soil and will not spread out laterally to any appreciable extent.

3. Laterals built diagonally down the slope have a tendency to approach a mean between the two methods mentioned above. Such a lateral has a steeper grade than that of the contour lateral and a lighter grade than that of the second method, thus the velocity of the water in the lateral is increased over that in the first and decreased under that of the second case. With this method water can be run a slightly greater distance than by

either of the first two methods mentioned before it must be changed.

There are two distinct methods employed in irrigating by wild flooding, each of which has its advantages and disadvantages. One method is to begin to irrigate with the lowest lateral and work up the hill. The advantage of this method is that there is always dry land upon which the irrigator can cross from one part of the field to another. The disadvantage is that all waste water recovered by a lower lateral must be turned upon land that has already been irrigated. The other method is to begin with the upper lateral and work down the slope. This method has the advantage that all waste water can be collected in a lower lateral and turned upon land that has yet to be irrigated. The disadvantage is that the irrigator has more or less wet ground where he is at work changing the water.

The spacing of the laterals varies with the degree of steepness of the land, the smoothness of the surface, the physical properties of the soil, the amount or head of water to be used, and the crop to be irrigated.

The initial cost of wild flooding is less than that of any of the other methods yet this is more than offset by the increased cost of handling the water upon the ground. The water requires more attention and more leading around with the shovel in order to cover all of the surface and must be changed at more frequent intervals. In addition this method can not be classed as an economical method as the water runs quickly over the surface and penetrates but slightly into the soil, it can not be distributed evenly over the land, and more or less water runs off the field and is lost.

19. Surface Pipe Method of Irrigation.—This method is an outgrowth of irrigation by pumping. It requires no ditches, check, or border levees nor is it essential that the surface be graded to a uniform slope. For these reasons it is rapidly gaining in favor in the East and is destined to become one of the most common methods of applying water under humid conditions. When irrigation is practised to supplement the natural rainfall during dry spells, relatively small quantities are needed. An application of 2 acre-inches per acre is usually sufficient at any

one time. Accordingly pipe mains ranging in size from 6 to 12 inches in diameter convey sufficient pumped water to the highest portions of the fields from which it is distributed through movable surface pipes attached to special hydrants or stands on the head mains. All main and head pipes are laid far enough below the surface so as not to interfere with the plow or subsoiler. When a field has been watered and the surface pipes removed, nothing remains to interfere with the ordinary processes of growing and harvesting crops until a second watering is needed. To be free from the inconvenience of an open ditch, levee, or other field obstruction and to be able to utilize the space which these occupy, are strong incentives to adopt this method. It is also well adapted to the irrigation of the rolling and irregular land surfaces of the Atlantic Coast States. As will be noted later the surface of fields should be carefully graded and smoothed

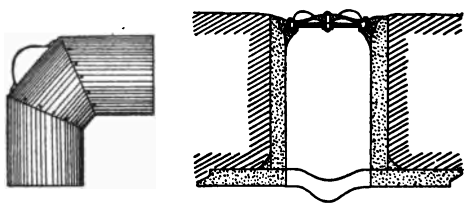

FIG. 39.—Stand and valve for irrigating alfalfa.

as a necessary preparation but only to a limited extent can this be done in the far East where the soil is too shallow to permit much surface grading.

This method as used in southern California for the irrigation of alfalfa is described by C. E. Tait in Bull. 236 of the Office of Experiment Stations, U. S. D. A., issued in 1912. Since then a number of improvements have been made to which the author of this publication has called the writer's attention. The concrete head pipes for alfalfa are usually 12 inches in diameter and are laid beneath the surface. About 100 feet apart, stands of the same material are inserted in the head pipe and at the top of each stand a valve is placed as shown in Fig. 39. The prices of alfalfa valves as made by the Irrigator's Supply Company of Ontario, California, follow:

Size of pipe, inches	Size of opening, inches	Weight, pounds	Price
10	7 1/2	7 1/2	$1.65
12	9 1/2	10 1/2	2.25
14	11 1/2	16	2.75
16	13 1/2	22	3.50
18	15 1/2	29	5.50

Standpipes which project a foot or two above the surface are seldom used in irrigating alfalfa. The more usual practice is to use only a portion of a joint of pipe for stands which terminate 4 to 6 inches below the ground surface. When the valve is protected by a covering of earth when not in use, wagons and other implements can pass over it without injuring it.

Hose and hose connections between the stands and the surface pipes have also been substituted for metal pipes and metal elbows. The detachable surface pipe is made of galvanized iron, usually 24 gauge. It is 8 inches in diameter and is made up in

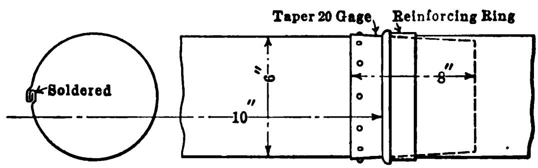

FIG. 40.—Surface pipe for irrigating from stands.

10-foot lengths. Each length consists of a single sheet of metal which is rolled, crimped, and soldered in the manner shown in Fig. 40. The socket end of each length is reinforced by a ring and the spigot end is formed by riveting a tapering joint 8 inches long of 20 gauge.

Mr. Tait states that with a head of 60 miner's inches (1 1/5 second-feet) one man can irrigate 2 1/2 acres in a 10-hour day. In irrigating a field the water is used from one stand for a strip equal in width to the distance between stands and in length from the head to the foot of the field. If one begins to irrigate at the upper end, he proceeds toward the lower end by gradually adding sections of pipe until the entire strip is watered.

Where the depth and fertility of the soil and other conditions will permit, it pays to grade alfalfa fields with as much care for this method as for any other. If the surface is left rough

and uneven the water can not be evenly distributed, causing dry spots on the high places and over-irrigation and scalding in the low places.

20. Border Method of Irrigation.—The border method is well adapted to the irrigation of alfalfa and grain crops and is used extensively in California and Arizona and to a less extent in Idaho, Montana and other Rocky Mountain States. It consists of dividing the field into a series of parallel strips or borders by low flat levees. It is especially adapted to land with a medium, uniform slope and to light open soils that absorb water readily. It can also be used best under canals which deliver water to users in large heads.

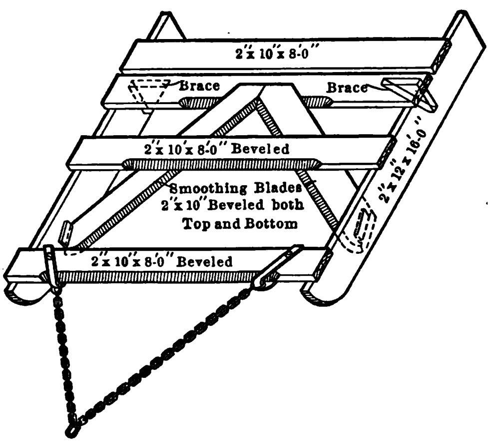

FIG. 41.—Home-made levee planer or smoother.

In preparing the land for border irrigation, the ground is first plowed or disked and the location of the levees is marked by plow furrows. A good foundation for the levees is made by plowing two or more furrows on each side of the levee line, the earth being thrown toward the center from either side. The levees are built with a Fresno scraper which is driven back and forth at right angles to the levee lines, the earth which is skimmed from the surface being dumped on the levee line so that the loads overlap one another. The levees after being roughly made by the scrapers are brought down to grade and smoothed by an implement known as a planer or smoother, Fig. 41. The levees

should be made so that after being smoothed and settled by water, they will be from 8 to 10 inches high in the center and have a base of 6 to 8 feet. This will permit the cutting and raking of hay with comparative ease. The cost of preparing border checks, including ditches and gates, ranges from $10 to $30 per acre.

The levees usually extend in the direction of the steepest slope. When the slope is too steep the borders are laid off diagonally across the face of the slope. A medium loam soil with an even grade of about 1 foot in 400 feet presents ideal conditions for the border method. For these conditions border checks 50 feet wide and from 600 to 800 feet long will be found desirable. Where the grade is steeper than 1 foot in 400 feet, the checks should be 30 to 40 feet in width. If the fall is less than that

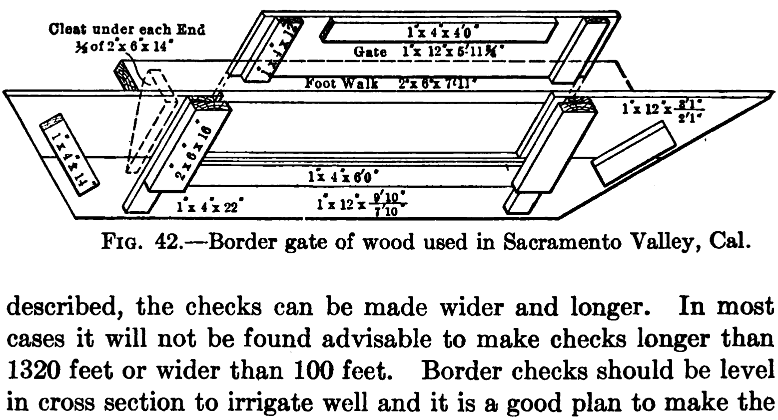

FIG. 42.—Border gate of wood used in Sacramento Valley, Cal.

described, the checks can be made wider and longer. In most cases it will not be found advisable to make checks longer than 1320 feet or wider than 100 feet. Border checks should be level in cross section to irrigate well and it is a good plan to make the first 25 or 50 feet of the upper end of the check level in both directions. This causes the water to spread evenly between the levees when leaving the head ditch, thus allowing it to flow down the check in a thin sheet.

The head or feed ditch should be located so that two or more border checks can be watered at the same time. The size of the ditch will naturally depend upon the grade that can be secured and the quantity of water to be carried. For ordinary farms of 10 to 40 acres, the feed ditch should be at least 4 feet wide on the bottom and excavated about 1 foot below the ground surface, the banks being about 2 feet high.

Water is admitted to each check through a gate or box placed in the ditch bank. Fig. 42 shows a type of timber gate used extensively in the Sacramento Valley, California. Another more substantial gate built of concrete is shown in Fig. 43. The ordinary head of water turned into each check usually varies from 1 to 5 cubic feet per second. The advantage of the larger head is that the land can be covered more quickly and the cost of applying water is materially reduced. Water after being admitted passes over the check in a thin sheet and before reaching the lower end of the field, the check gate is closed, since there is then usually enough water flowing in the check to complete the irrigation. A drainage ditch is generally provided at the lower

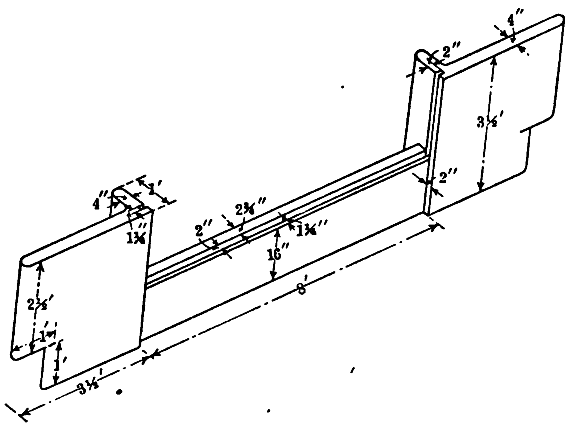

FIG. 43.—Border gate of concrete used in Sacramento Valley, Cal.

end of the checks to carry off surplus water. The average cost of applying water each time ranges from 10 to 25 cents per acre.

Ralph D. Robertson, irrigation engineer of the U. S. Department of Agriculture, who has had much to do with irrigation development in the Sacramento and San Joaquin valleys, California, is of the opinion that the sketch shown in Fig. 44 typifies the best practice of the border method as used in the Sacramento Valley. In this field the checks are 50 feet wide and 800 feet long. The levees are 8 feet wide on the bottom and 10 inches high. The slope is 1 foot in 400 feet, there being a difference of elevation of 2 feet between the upper and lower

end of each check. The soil is a silt loam and the cost of preparation was $15 per acre. The head ditch is 5 feet wide on the bottom, 2 feet deep, and has a capacity of 10 cubic feet per second. The following brief descriptions give some idea of the border method as practised in other localities.

Under the Sutter Butte canal in the Sacramento Valley, California, the feed ditches are designed to carry from 10 to 15 cubic feet per second and irrigation progresses at the rate of

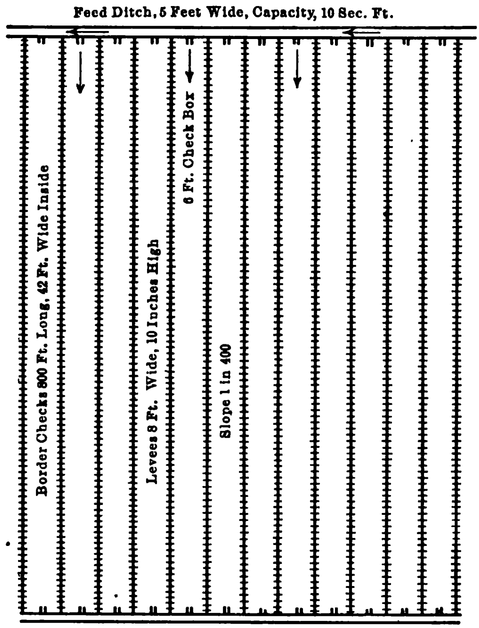

FIG. 44.—Alfalfa field near Gridley, Cal., irrigated by border method.

2 acres per hour with two men handling the water. Usually from 2.5 to 5 cubic feet per second are turned into each check. The cost of each watering is about 20 cents per acre. When irrigation was first practised in the Turlock and Modesto districts, California, the land was prepared in rectangular and contour checks. Of late years the border method has grown in favor. The time allowed the irrigator in these districts for a head of water of 10 to 15 cubic feet per second varies during the season from 20

to 30 minutes per acre. The average cost of applying water for the season is about 50 cents per acre. In Yolo County, California, where the border method originated, a common head of water delivered to the irrigator is from 10 to 12 cubic feet per second. Average checks having a fall of 1 foot in 400 feet are made 50 feet wide and 1320 feet long. The cost of applying water is from 10 to 20 cents per acre for each irrigation. In the Imperial Valley, California, the cost of preparing border checks, ditches and gates is from $5 to $20 an acre and where much native vegetation has to be removed, the cost may reach $40 per acre. The checks vary from 50 to 75 feet in width and in length up to 1320 feet. Two cubic feet per second represent the average head turned into each check. In Salt River Valley, Arizona, borders are made from 30 to 50 feet wide and from 1/8 to 1/4 mile long. A head of water of about 100 miner's inches is turned into a check 30 feet wide and 660 feet long requiring from 1 to 3 hours to complete an irrigation.

21. Check Method of Irrigation.—This method consists of dividing the field into a number of small compartments surrounded by low levees. Provision is usually made to flood each check by means of a gate or box placed in the ditch bank. This method is well adapted to light sandy soils having a rather uniform slope of 3 to 15 feet to the mile, but is used also in heavy soils where it is necessary to hold water in the checks to secure its percolation downward. There are various modifications of the check system in use. When the levees follow the natural contour of the ground surface, the enclosed spaces are called contour checks. Fig. 45 shows a 40-acre field prepared by the contour method in which the single lines represent the levees built on the contours and the double lines, the field ditches. Cross levees are constructed to break up some of the larger checks, making the average size of each compartment 1 acre or less in extent.

Before the checks can be formed, it is necessary to make a survey to determine the location of the levee lines and the field ditches. Engineers follow somewhat different methods of conducting a survey of this kind but the general operation and the end attained are the same. A party of three consisting of a levelman, rodman, and a man following with a plow can work

to advantage. The levelman sets up his instrument where he can command a good view of the field and takes a number of random readings at different points to gain a general knowledge of the topography. He then selects a point on the highest contour and takes a reading on a hub or stake driven flush with the ground. This stake may be referenced, to be used as a benchmark for future surveys. The levelman after noting the rod reading calls this the grade rod and locates points of the same elevation by having the rodman proceed over the field with the target set at the initial reading. The rodman marks each point with a stake and the plowman follows closely behind connecting up each point with a furrow which marks the location of the levees. When the rodman has reached the end of the field, he

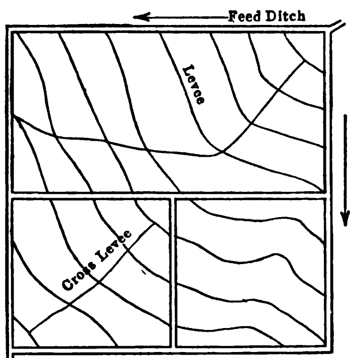

FIG. 45.—Forty-acre field showing contour checks.

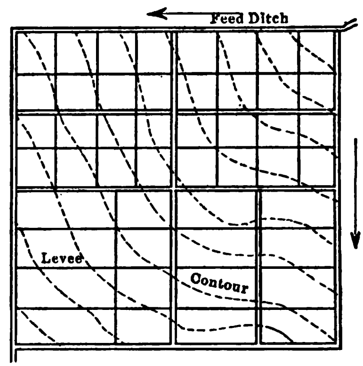

FIG. 46.—Rectangular checks on field shown in Fig. 45.

moves the target up the correct distance from the contour interval decided upon and starts across the field a second time, locating the new contour line, the plowman following as before. Three or 4 inches is the usual vertical distance between contours and it will not be found advisable to contour land that slopes more than 2 feet in 100 feet. The height of the levees depends upon the difference in elevation of the contour lines and the depth of water applied in one irrigation. As a rule levees 8 or 9 inches high after being settled and with a base of 6 to 8 feet will be found satisfactory. These offer but little difficulty in cutting and harvesting crops while high levees are often troublesome in this respect.

Rectangular checks are often preferred to the contour type. Fig. 46 shows the same field as that sketched in Fig. 45 prepared by building the levees in straight lines thus forming a series of rectangles. In either case the levees are generally made by scrapers drawn by two or four horses. The high parts within the checks are removed to the lower spots or dumped along the levees. The proper leveling of each check is important. The size of the checks depends largely upon the slope of the land, the character of the soil and the head of water available. In the San Joaquin Valley, California, where the check method is used more extensively than in any part of arid America, the average size of the checks is about three-fourths of an acre. It was the common practice when irrigation commenced in this valley to make large checks containing sometimes as much as 25 acres in a single check. Later practice has demonstrated the fallacy of this idea and large checks with their correspondingly high levees containing over 5 acres are now seldom found in California.

The cost of checking land for irrigation including ditches and structures ranges from \$10 to \$30 per acre and the average over a large part of the San Joaquin and Sacramento Valleys is about \$15 per acre. In the Tulare Irrigation District, California, alfalfa is irrigated by the check method with a head of water varying from 5 to 10 cubic feet per second at a cost of about 50 cents per acre. The cost of each watering on large areas of land under the Miller and Lux canal system in Fresno and Merced counties where contour checks are used is from 75 to 90 cents per acre. An irrigating head of 5 cubic feet per second will cover 1 acre about 5 inches deep in 1 hour and at this rate 10 acres per 10-hour day can be irrigated. Suitable boxes for controlling the water passing from the feed ditch into each check greatly lessen the time required and facilitate the ease of irrigation.

22. Basin Method of Irrigation.—This method is essentially the check method adapted to the needs of orchard irrigation. Ridges of loose earth are thrown up midway between the rows of trees in two directions at right angles to each other. These form a large number of square basins, or enclosures, with a tree at the center of each. The ridges are made either by throwing up two furrows with an ordinary walking plow or with a special implement known as a ridger. There are various forms of ridgers

used, the most common of which is shown in Fig. 47. It consists of two running boards made of 2-inch plank, 14 to 18 inches high and from 6 to 8 feet long. The runners are shod with steel on the bottom and part way up the inner side to prevent wear and lessen the draft. They are from 4 to 5 feet apart at the front end, 15 to 24 inches apart at the rear end, and held in position by cross pieces and straps of steel. Another implement popular in California for making ridges is the rotary disk which throws the earth toward a common ridge in the center and requires only one trip across the orchard for each ridge. In cross checking or ridging the orchard an opening is left at each corner of each basin. An ordinary scraper or a rotary scraper is usually used to fill these gaps or openings; occasionally they are filled with a

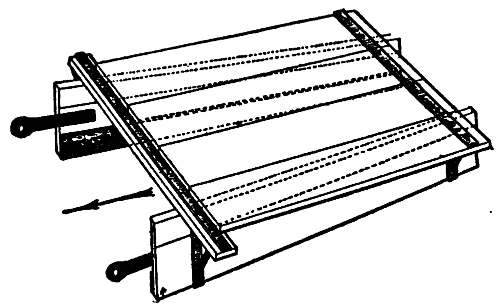

FIG. 47.—Ridger used in basin irrigation.

shovel. The ridges are made from 4 to 9 inches high depending upon the depth of water applied in one irrigation.

There are several methods of flooding basins practised. One of the most common and perhaps the best method is shown in Fig. 48. Double ridges are made between alternate rows of trees, forming a small ditch through which water is conveyed from the head ditch in the direction of the greatest slope. The basins are flooded in pairs beginning with the lowest tier. Another method of flooding basins is to let the water from the feed ditch take a zigzag course through the basins by making openings in opposite corners of each compartment. The principal objection to this method is that the basins nearest the head ditch receive the most water. To prevent water coming in contact with the trunks of the trees, which is considered detrimental

by some orchardists, ridges may be formed between the rows of trees. These form small basins around each tree, the water being applied to the outer basin. Ordinarily the orchard can be graded leaving a small mound around each tree high enough so as never to be submerged.

After each irrigation the ridges are worked down to the general ground level and the orchard is thoroughly cultivated and harrowed. The average cost of preparing the land for basin irrigation in the Santa Clara Valley, California, where this form of irrigation has reached its highest development is about 70 cents per acre and the average cost of applying water is about $1.90 per acre. The basin method was formerly used extensively in southern California for the irrigation of citrus fruits but has

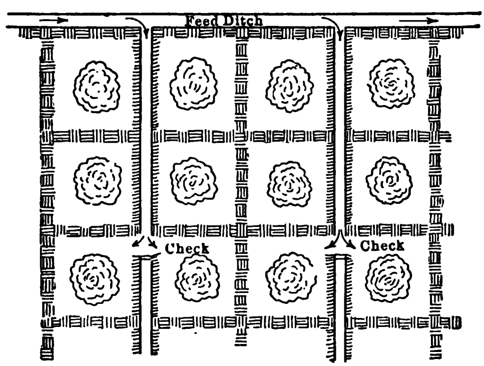

FIG. 48.—Basin method of irrigation.

been practically abandoned in favor of the furrow method. It is, however, still used on some of the heavier clay soils and for the irrigation of numerous walnut orchards.

23. Subirrigation.—Crops are said to be subirrigated when the irrigation water is supplied from beneath the surface and is drawn to the roots by the force of capillarity. The water used in subirrigation may be supplied in two general ways. First, through some form of artificial conduit, such as tile or cement pipe, and second, by raising the natural water table high enough so that the plants can draw upon it for their growth. The first may be termed artificial subirrigation and the second natural subirrigation. In either case at least three conditions must

exist in order to make subirrigation practicable: namely, a porous surface soil which allows rapid movement of the moisture laterally or upward; an impervious substratum, and drainage facilities to prevent the complete waterlogging of the land. There are few localities where these three conditions exist simultaneously and the area of land adapted to subirrigation is therefore very restricted.

Artificial Subirrigation.—Artificial subirrigation has always seemed very attractive to the uninitiated since it is in theory an ideal method of distributing the water in the soil. It reduces to a minimum the usual waste due to evaporation and run-off, the water can be easily controlled and the cost of application is small. However, unless the conditions described above prevail the installation of a subirrigation system is very apt to result in failure, and even when all conditions are favorable, the high cost of installation makes this method of irrigation unadvisable unless valuable crops can be grown.

Perhaps the most successful subirrigation is practised in the vicinity of Sanford, Florida. The following description of the methods employed in Florida and other sections has been extracted from a report by Milo B. Williams, Irrigation Engineer, of the U. S. Department of Agriculture.

The lands in the vicinity of Sanford, Florida, are sandy and slope gently toward the lake with an exceptionally uniform surface. They are known as the "Palmetto Flatwoods." The soil is sandy and is underlaid by hardpan which is a decided advantage from the standpoint of subirrigation since it forms a bottom for the moisture reservoir, thus holding the water close to the plant roots and assisting greatly its lateral spread. Water is turned into the irrigation systems from flowing wells and allowed to run until the whole soil area is saturated to the surface. Then the tile drains are opened and the excess is allowed to drain off. This is done at times of setting out young plants rather than during the growth of the crop.

As the larger part of the land is naturally too wet for cultivation and must be drained as well as irrigated, the system of tiling used is designed to answer both purposes. The tile system consists of a water-tight main pipe feeding a series of open-jointed parallel laterals placed 16 to 18 inches deep. The mains

FIG. A.—Main line and stop-boxes for subirrigation systems

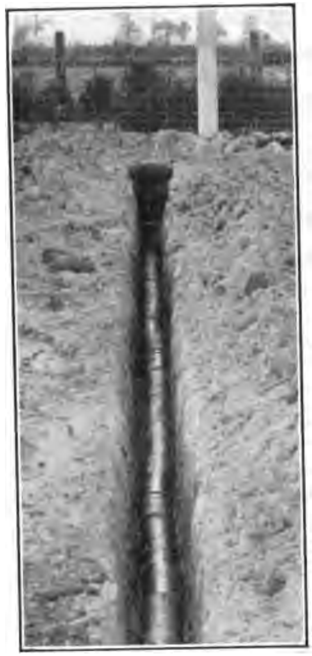

FIG. B —Lateral line and stop-box.

FIG. C.—Details of stop-boxes.

(Facing page 96.)

are laid parallel to the surface regardless of grades and are located on the highest side or on the ridges throughout the field so that the laterals slope away from the mains at the proper depth. The mains are 4-inch to 5-inch vitrified terra cotta pipe which is obtained in 2 1/2-foot lengths with bell ends. The joints are made water-tight with cement. A stop-box is placed at the intersection of each lateral with the main. Holes are cut in the side of the pipe and a short length of 2-inch steel pipe is cemented into place to form a connection between the main and the head stop-box, the lateral leading out from the stop-box. This metal pipe also forms a neck in which wooden plugs or other devices may be inserted to control the flow of water.

The laterals are built of 3-inch clay drain tile which are obtained in 12-inch lengths. The pipe are laid with open joints by placing the short lengths end to end. A shovelful of sawdust or cinders is placed over each joint to prevent fine sand from working into the line and stopping up the pipe. The grades for the lateral trenches vary from a 1/2-inch to a 3-inch fall per 100 feet and the laterals are spaced 18 to 24 feet apart, the shorter distance being preferable.

Stop-boxes (Plate III, Fig. A) are placed in the lateral lines (Plate III, Fig. B) at intervals of 100 to 400 feet for the purpose of checking the water in the laterals and thus securing a small pressure in the line above the boxes. A weir division wall (Plate III, Fig. C) is inserted near the inlet side containing two metal-lined openings, one a 3-inch hole on a level with the tiles entering and leaving the box and the other a 1-inch hole about 6 inches higher. When the water is not to be held in the pipe line above a box, the lower hole is left open so that the water can pass down the line freely. When the water is to be held up, the lower hole may be plugged, raising the water to the upper hole, or both may be plugged, causing the water to rise until it flows over the top of the weir wall into the next section of the lateral. The cost of this system ranges from $100 to $125 per acre, not including the water supply or the drainage outlet from the field.

The first irrigation usually is applied when the first winter crops are planted in the fall. Later irrigations occur at intervals of 10 days to 2 weeks thereafter during the growing period. The length of time required to saturate the Sanford soils varies

from 2 or 3 hours to 24 hours depending on the amount of water in the soil prior to irrigation, the depth to hardpan and the texture of the soil.

Some of the peat lands of Florida are also subirrigated. Owing to the lower first cost and the difficulty in keeping the tile in alignment in the spongy peat, many of the farmers in this section use wood conduits in place of tile (Fig. 49). Open ditches are used for the main supply and drainage conduits. The laterals are made of rough pine lumber. Boards 1 × 6 inches are spliced together with cleats and laid in the bottom of the lateral trench with the cleats underneath. Small 1/4-inch blocks are then nailed along the top edges at intervals of 2 1/2 feet. Boards 1 × 4 inches and 1 × 5 inches are nailed together forming a V-shaped trough which is inverted over the

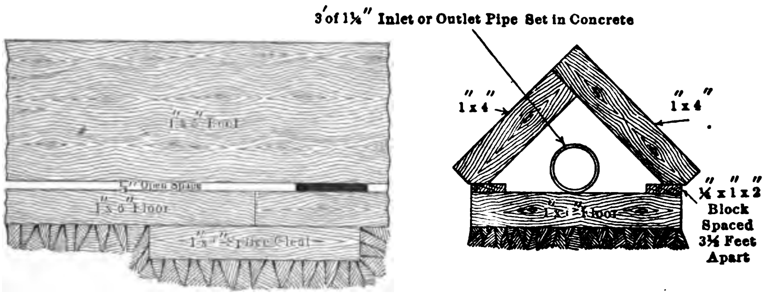

FIG. 49.—Wooden conduits for combined drainage and irrigation.

boards in the trench and the water enters and leaves through the triangular cavity thus formed. The laterals are spaced 15 feet apart, 15 inches deep and on a slight grade or no grade. Three-foot lengths of 1 1/4-inch galvanized steel pipe are placed in the ends of each lateral through which the water is turned into or discharged from the lateral. Wooden plugs are used in the ends of the pipe for diverting the water from the open ditches to the laterals. With lumber at $16 per thousand feet B. M., this construction costs $90 per acre.

Subirrigation from open ditches is also practised in Florida, this method being adapted to very level land and for shallow-rooted crops. It is necessary to drain this land during the summer season and to irrigate it during the winter. The

drainage is done through surface ditches cut 3 to 5 feet deep. The fields are drained into the border ditches by surface laterals which are also used as irrigation laterals.

The land is prepared for irrigation and drainage by throwing the soil into ridges 12 to 13 inches high and 4 feet apart. Irrigation laterals are placed at intervals of 40 feet running in the direction of the rows. Grades are very flat and the water is held in the ditches by earthen dams until the moisture shows on the surface over the entire area between ditches.

Various modifications of the Florida system of pipe subirrigation are found in scattered localities throughout the central and middle western states, chiefly in Kansas, Colorado, and Texas.

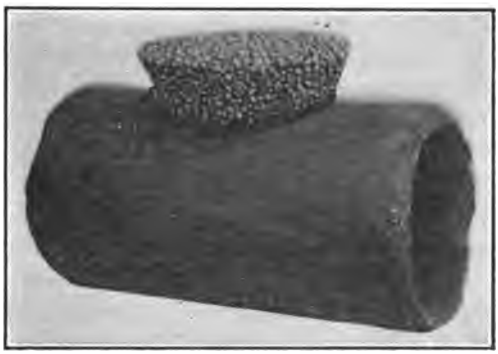

Fig. 50.—Cement pipe for subirrigation, showing porous nozzle.

Porous concrete tile for subirrigation has not proved very satisfactory owing to the fact that the coarse structure permits the free absorption of soluble substances from the soil, many of which react with the cement and cause it to disintegrate. There is also danger that the sediment carried by the water will clog up the pores in the pipe and lessen its porosity.

Continuous concrete pipe has also been used to some extent but owing to the fact that it is difficult to make it strong enough to withstand stresses due to expansion, contraction, and earth pressure, this kind of pipe is not likely to come into general use. From an hydraulic standpoint, non-porous pipe with protected and adjustable openings would seem to be a logical type of construction.

Several devices are used to protect the pipe openings against the entrance of roots and dirt. In one of these devices small concrete nozzles, each having an opening through its length are inserted in the top side of the pipe. Each nozzle is covered with a concave concrete cap cemented at each end but left uncemented on the sides so that the water can seep out. The distribution of water is controlled by varying the size of the nozzle openings to suit the different hydraulic pressures. Another device consists of a circular block of porous concrete having a convex top and a concave bottom with the bottom so hollowed as to form a cavity (Fig. 50). This is cemented over an opening in the pipe. The top of the block is waterproofed with neat cement so that water seeps through the porous concrete and enters the soil through the sides of the block. The discharge is regulated by increasing or decreasing the size of the block.

Before a subirrigation system is installed, preliminary tests should be made on a small area of the tract to be irrigated. These tests should determine the amount of water required by a given subirrigated area, the depth to which the water percolates beneath the laterals and the distance to which it spreads laterally. When it has been determined how far apart to space the laterals the cost can be determined quite accurately.

Subirrigation of lands which contain any considerable quantities of soluble salts involves great risks since the continuous rising of moisture from below may cause an accumulation of salts on the surface which will in time make the land unproductive.

Natural Subirrigation.—Frequently the seepage water from porous, earthen ditches and the waste water from irrigated areas pass through the subsoil of lower fields sufficiently near the surface to subirrigate them. In other places these seepage waters collect at the lower levels and raise the ground water near enough to the surface to supply the plants with the needed moisture.

Perhaps the most notable subirrigated area in the arid region is found in the vicinity of the towns of St. Anthony and Sugar City in the upper Snake River Valley, Idaho. This subirrigated district comprises an area of about 60,000 acres. The surface soils in this area are gravelly or clay loam, varying in depth from 1 1/2 to 6 feet. The land slopes at the rate of about 10 feet

per mile. An impervious lava rock is found at a depth varying from a few feet to 90 feet. This land was at first irrigated by the usual methods but owing to the porous nature of the soil the water rapidly sunk to the bed rock and it was not possible to retain sufficient moisture in the surface soil to insure good crops. In time, however, the subsoil filled with water and the top soil began to receive moisture from below. This led to a new method of irrigation. The water is supplied to the fields in shallow ditches 3 feet wide, 6 inches deep and not to exceed 1320 feet long. These ditches divide the farm into strips 100 to 300 feet wide. By this method no water is spread over the surface, the laterals merely distributing from 15 to 20 miner's inches to different parts of the field where it soon joins the ground water by sinking through the bottoms of the shallow ditches. The water is kept running continuously until the water table rises high enough to supply the needed moisture to the roots of the plants. Thereafter the ground water is regulated by the amount of water turned into the supply ditches. The rise and fall of the ground water is determined by means of small boxes set in the ground 3 to 5 feet deep. From 20 to 30 boxes are usually required for each 80-acre farm.

A system of subirrigation very similar to that just described is practised in parts of the San Luis Valley, Colorado. The best results are obtained on porous sandy loam soils underlaid at a depth of several feet by an impervious stratum and on land having a slope of 5 to 10 feet per mile. Most of the land in the valley is of uniform slope and the custom is to run the ditches parallel to the section lines in the direction having the least slope. They are spaced at intervals varying from 50 to 250 feet according to the character of the soil, the depth to the normal water table and the amount of irrigation in the neighborhood affecting the water table.

There are many modifications of the above method in the San Luis Valley. Where the soil is thin or leveling is impracticable for any reason, the field ditches are carried along the ridges. In the river bottoms, sloughs or old channels are dammed and kept full of water during the season. In other cases small reservoirs have been built to catch excess water which is allowed to seep out and saturate the subsoil.

24. Spray Irrigation.—In spray irrigation water is applied to the surface of soils and crops in the form of rain or mist. This method has long been used in the irrigation of lawns in western cities. When one considers the high rates charged by companies and municipalities for domestic water supplies and the large percentage of such supplies which is used for sprinkling lawns he is surprised at the crudeness and inefficiency of the equipment and methods employed.

In recent years successful attempts have been made not only to improve the practice of spray irrigation but to extend its use to gardens and fields. In outlining its broader scope in the irrigation of fields, the writer has been guided by the recommendations made by Milo B. Williams, to eastern irrigators in assisting them to install suitable plants for the irrigation of small areas throughout the humid region. These plants are designed to supplement a scanty or unequal and always uncertain rainfall by furnishing relatively small quantities of water to truck, small fruit and orchards at the right time. The large profits derived from such crops, the high cost of artificial fertilizers, the uneven character of the surface of fields, the growing of two or more crops on the same field in one season and the advantages of being able to control the soil moisture in cultivating and recropping, fully justify, under favorable conditions, the heavy expense.

The essential features of every system designed for spray irrigation are (1) nozzles, (2) feed pipes and (3) a pumping plant or its equivalent. The design of nozzle and its arrangement in the field separate the types of spray irrigation into three more or less distinct groups which are herein briefly described under the following heads.

PORTABLE NOZZLE TYPE.—This consists of sets of nozzles and hose which can be moved from place to place and attached to hydrants conveniently located throughout the field. The hydrants are generally spaced 100 to 200 feet apart and each controls an area of proportionate size. The hydrants are usually made of a short length of pipe projecting 2 or 3 feet above the surface and capped with spigot or hose connection. In some cases special hydrants are used. The portable nozzles are attached to lengths of hose which reach at least one-half the dis-

tance between the hydrants. For garden or lawn irrigation a 3/4-inch hydrant and hose can be used. Grass sods, such as putting greens, public parks, and meadows are often irrigated with larger hose ranging up to 2 1/2 inches in diameter.

Some gardeners prefer to dispense with the nozzle in spraying greenhouse plants and seed-beds, and merely pinch the end of the hose between the fingers in such a way as to produce the desired spray. There are a number of adjustable nozzles on the market which can be made to discharge a solid stream or any degree of fineness of spray. One type requires to be held constantly in the hand or moved very frequently. Another type which sprays a circular area can be set in one place and allowed to run for some time before moving is necessary. The last type is generally supported on a stool or sharp-pointed rod which can be stuck into the ground and the nozzle held 3 or 4 feet above the surface.

Where a large quantity of water is to be applied through a large hose, a rotating nozzle mounted on a small truck meets the requirements. These nozzles discharge from 60 to 100 gallons per minute under a 30-pound pressure and cover a circular area 75 to 100 feet in diameter.

STATIONARY NOZZLE TYPE.—The stationary type of spray irrigation consists of a system of equally spaced nozzles over the field so that any portion can be sprayed by turning on the water. The feeder system forms a network of piping so constructed that the nozzles are about 30 feet from each other and set on the "diamond." This makes the circular areas covered by the nozzles fit together with the least overlapping and yet cover the bulk of the ground. The nozzles are placed on 3/4-inch risers 5 to 6 feet above the surface. The nozzles commonly used may be divided into three groups, viz., (1) solid nozzles with no moving parts, (2) adjustable nozzles with parts which can be manipulated to change their capacities or degree of spray and (3) rotary nozzles with moving parts which assist in the distribution of the water by centrifugal forces.

The capacities of some of the popular nozzles were found by actual test to be from 3.2 gallons per minute to 14.5 gallons per minute when operating under 20 pounds pressure per square inch, and from 3.5 to 18.4 gallons under 25 pounds pressure. The

circular areas covered by the different nozzles varied from 30 to 40 feet in diameter. The distribution of water over the areas was somewhat uneven. Most nozzles discharge a relatively large percentage of the water in an annular ring from 10 to 30 feet in diameter, with gradual reductions inside and outside of this ring.

The solid nozzles with no moving parts are the most durable. Their capacities and form of spray can not be varied as in the case of the adjustable nozzle. The solid nozzles which will give a wide lateral throw are of large capacities and demand large feeders.

Rotary nozzles throw the greatest distance in proportion to their capacities but in larger drops. A certain amount of wear takes place which in time reduces their efficiencies.

Adjustable nozzles are favored by some truck gardeners because of the fine spray which can be obtained when desired. The throw is usually less than either the stationary or rotary nozzle.

Overhead Nozzle Lines.—The system commonly known as overhead spray irrigation consists of a series of nozzles inserted in parallel pipe lines supported above the surface on posts in such a way that each line is fed from a main at one end and irrigates a strip from 50 to 56 feet in width the length of the field (see Plate IV).

A nozzle line is made of galvanized wrought iron or steel pipe into the shell of which is screwed at regular intervals small brass nozzles. The pipe is supported in bearings which will permit it to be revolved, thus throwing the nozzles from side to side. The nozzles are accurately set in a straight line so that all will discharge in the same direction and irrigate a strip parallel to the pipe when the line is set in any one position. Consecutive strips can be irrigated by revolving the pipe through an arc at different stages until the entire area on both sides is covered. Each nozzle throws a clear cut solid stream which becomes broken into small drops before reaching the ground. A nozzle line is connected to the feed pipe by means of a riser, elbow, patented turning union, and nipples. A quick-opening lever gate valve is placed in the riser at a convenient height. The lines are operated from the feeder end by a hand or power turning device.

The nozzle lines should run in the direction of cultivation so that the crop rows will parallel the pipe supports. The feeder

PLATE IV

FIG. A.—Overhead spray irrigation showing piping.

(*Facing page* 104.)

FIG. B.—Enlarged view of overhead nozzle line.

pipe should run under ground at right angles to the nozzle lines and be so located as to use the least amount of large pipe.

The size of pipe to use in a nozzle line is determined by the number and capacities of the nozzles it contains. The end connecting to the feeder is the larger to carry all the water but as the water is diminished by the nozzles the pipe can be made smaller in proportion to the amount withdrawn.

The following table illustrates the sizes of pipe used in nozzle lines of different lengths for a nozzle having a capacity of 1/5 gallon per minute and a spacing of 4 feet.

TABLE No. 17

Total length, feet	Proportioned sizes and lengths of pipe				
	3/4 Inch	1 Inch	1 1/4 Inch	1 1/2 Inch	2 Inch
100	100	....	....	....	....
150	90	60	....	....	....
200	90	110	....	....	....
300	90	150	....	....	....
400	90	150	160	....	....
500	90	150	150	110	....
600	90	150	150	150	60
700	90	150	150	150	160
800	90	150	150	150	260

Nozzle lines are usually spaced 50 to 56 feet apart and operated under 30 pounds pressure. When it is desired to irrigate more rapidly larger pipe lines and nozzles must be used or the small nozzles may be spaced closer together on a larger pipe. It seldom pays to use 2-inch pipe in nozzle lines but is cheaper and better to run more feeders.

There are two popular methods of supporting nozzle lines, *i.e.*, directly on posts or suspended from a high cable. A post which will hold the pipe just above the crop or one that elevates the line 6 1/2 feet above the surface so a horse can pass under are the common designs. The higher design permits cross cultivation and is popular among truck farmers and berry growers, while the low posts place the system less in sight for flower beds, lawns and small home gardens. The posts should be of concrete, pipe, or wood treated with asphaltum, tar, or paint. They should be 5 to 6 inches at the base if of wood, and set in the ground 2 1/2 to 3 feet and of ample length to be cut off at the right height

after set to give the nozzle lines uniform appearance. Nozzle lines should be supported every 18 feet.

Suspending the nozzle lines from a high cable supported on large posts is a construction used by some farmers because of the less obstruction to cultivation. The posts are spaced from 75 to 100 feet apart and may be either of wood or 4-inch steel pipe. They should be from two to three times as high as the pipe is to be held. The cable is held on the tops of the posts by heavy hooks but free to draw lengthwise. Heavy spreading anchors must hold the ends of the cable which are generally fastened to buried logs or concrete. A turn buckle should be inserted near the end of the cable for use in taking up the slack at different times. The proper weight of cable to use depends upon the spacing and height of the posts and the weight of pipe to be supported. These facts should be furnished to the cable dealer and a sufficient weight used.

The nozzle line is suspended from the cable by varying lengths of galvanized wire spaced 15 feet apart and fastened to hooks in which the pipe lies. The nozzle lines can be graded uniformly by adjusting the lengths of the wire hangers. Cable suspension generally costs 15 to 20 per cent. more than direct post support.

FEEDER SYSTEM.—The designing of a feeder system should be governed by the type of nozzles used, their individual capacities, and the amount of water to be carried through each line. The field should be divided into irrigation units. The size of units will be limited either by the available water supply or by the rate of irrigation desired for the entire field. The main feeder should be located to make it as short as possible and at the same time intersect the branch feeders at the most efficient points. The capacity of the main should be equal to that of the pump and that needed for one irrigation unit. The main can be reduced in size as the water is diminished by branches in the most remote unit.

The branch feeders should be of capacities to supply their respective nozzles and reduced in size in correspondence to the amount of water to be carried at different points. No pipe should be small enough to generate excessive frictional resistance.

The following table gives the size of metal pipe to use for different quantities of water in order to keep the frictional resistance within moderate limits, for straight pipe lines under 500 feet in

length. For longer lines it is generally advisable to increase the sizes to the next larger. Allowance should also be made for any sharp bends.

TABLE NO. 18

Gallons per minute	Size of pipe, inches	Gallons per minute	Size of pipe, inches
5	1	350	5
10	1 1/4	400	6
20	1 1/2	500	6
30	2	600	7
50	2	700	7
75	2 1/2	800	8
100	3	900	8
150	3 1/2	1000	9
200	4	....	..
250	4	....	..
300	5	....	..

The pipe used for feeder systems consists of common steel or wrought-iron water pipe with threaded joints, or cast-iron pipe with leaded joints, or riveted steel pipe with flange or bolted joints. Reinforced concrete pipe can also be used for this purpose if it is properly made and the pressure is carefully regulated.

Steel pipe should be galvanized and the exposed threads on both steel and wrought iron should be painted. Black guaranteed wrought-iron pipe is more durable than steel and often used in preference to galvanized steel. The rust which forms on black pipe may give some trouble in filling nozzles. It is customary to use steel or wrought pipe in sizes up to 5 or 6 inches. Cast-iron pipe becomes cheaper for larger sizes unless it must be shipped long distances. Cast iron is the most durable of these metal pipes and may be used in the lightest weights made. Riveted steel pipe is light in weight and comes in long lengths making it the cheapest to lay. This pipe if well galvanized after making is good to use when long shipments and large pipe are necessary.

All feeder systems should be put underground below the depth of cultivation where possible, and ample provision should be made for draining in winter and for flushing out once or twice per year to blow out rust scales, sediment, etc. This is best accomplished by having removable plugs at the end of each main and feeder and at all low points in all lines.

Pumping Plants.—The five factors to be considered in designing a pumping plant for spray irrigation are the amount of water to be pumped per minute; the static head, or vertical distance between the level of the water supply and the highest nozzle; the friction and velocity heads or the total resistance to the water passing through the pipe lines; and the pressure head, or the amount of pressure necessary to operate the nozzles.

The capacity of the plant should be the same as that of the feeder system (see page 106). The static head should be determined by a survey in the field with an engineer's level and due allowance made for the distances the water level may be lowered when pumping as well as the height of the nozzles above the ground. The frictional and velocity heads can be obtained from hydraulic tables when the kind, size, and length of pipe and the amounts of water are known. The pressure head is determined by the type of nozzle used.

Knowing the capacity and the sum of the heads, the amount of work which the plant must perform is determined and the horsepower can be calculated to correspond to the guaranteed efficiency of the pump to be used.

The most desirable type of pump to use in any one case must be determined by the above factors and any restricting conditions of the water supply, such as a deep well, water containing sediment, etc. All factors and conditions should be furnished to several manufacturers so that they can bid on their most adaptable machinery and the farmer obtain the most efficient equipment for the expenditure.

Power displacement pumps of the piston and plunger types, and high pressure centrifugal pumps are the designs commonly used for spray irrigation plants.

The single cylinder displacement pumps are adaptable to small plants up to 75 gallons per minute, where the water is within 25 feet of the pump. This type is sometimes the only one advisable to use in deep wells for any quantity of water. The piston should be double acting and lift water when moving in either direction. The pump should be equipped with a large air chamber which will act as a cushion and reduce the pulsations of the water in the pipe lines to a minimum. The power head and cylinder are built in a compact unit for low suction lifts but must be sepa-

rated for deep well use. In the latter case it is best to have the cylinder always under water if possible.

The duplex and triplex displacement pumps are adaptable for pumping any quantity of water where the suction lift is within 25 feet. These pumps are built in both single- and double-acting types. Light weight double-acting duplex and single-acting triplex are commonly used. Smaller air chambers in comparison to the amount of water can be used than on simplex pumps as the multicylinders give a more steady discharge. These pumps are considered the most efficient types when kept in repair and direct-connected to the prime mover. The connection to the engine should be made by a friction clutch which can be thrown in or out at will when the engine is running. A belt connection can be used where desirable but takes more floor space and more power is lost in transmission. A direct-connected unit is the most efficient and compact construction. The reduced power necessary to run an efficient high-priced pump may make it cheaper to install and operate than a belt-connected inexpensive pump which demands a larger engine and house.

Centrifugal pumps can be used to advantage for spray irrigation under some conditions. Large centrifugal pumps are more efficient than small ones. Centrifugal pumps also decrease in efficiency as the head against which they must work increases. Therefore, the larger the plant and the lower the lift the more adaptable is a centrifugal pump. Where the total head does not exceed 100 feet a single-stage high-pressure pump may be used. These pumps should be built for high speed with long bearings and adequate oiling facilities. Two-stage centrifugal pumps should be used for heads between 100 and 250 feet as they can be run at lower speeds than the single stage for like heads.

The efficiency of a centrifugal pump may not be as high in the beginning as a good displacement pump but unless the displacement pump is kept in the best of repair its efficiency is apt to drop below that of the centrifugal which maintains its efficiency longer under wear. The centrifugal is the simplest of pumps and the repair bills are correspondingly small. It is seldom that a centrifugal can be direct connected to the prime mover unless the power is electricity in which case the centrifugal should always be considered.

CHAPTER V

WASTE, MEASUREMENT, DELIVERY AND DUTY OF WATER

25. The Low Efficiency of Irrigation Water.—The area of land irrigated in the United States at the present time (1914) is about 15,500,000 acres. Probably not less than 75,000,000 acre-feet of water are diverted annually from streams, reservoirs, wells and other sources of supply to water this area. Some idea of the magnitude of the amount of water supplied for irrigation may be formed by stating that if spread evenly over a territory the size of the State of New York it would cover it to a depth of over 28 inches. To convey so much water often from distant sources and distribute it over cultivated land render necessary a large number of canals and ditches. These channels are for the most part excavated in earth and except in a few cases a large percentage of the water which flows through them is lost by absorption and percolation along the route. Coupled with the transmission losses are to be found other losses arising from improper methods of use and lack of skill in applying water. An estimate of all losses based on water measurements and experiments shows that for every 3 gallons of water diverted from natural streams, only about 1 gallon subserves a useful purpose in nourishing plant life. In other words, the general average efficiency of irrigation water is less than 35 per cent. The waste which lowers the efficiency to one-third the maximum is all the more to be deplored by reason of the fact that irrigation water so valuable to the West is rapidly becoming scarce while fertile raw land without a water right is plentiful and cheap. Based on the acreage which a unit of water now serves, it is doubtful if more than 50,000,000 acres can ever be irrigated. The Census returns for 1910 show that in the 17 states comprising the arid region, 173,000,000 acres were classed as improved farm lands. Just how much more land can be improved of the total extent of arable land in the West is not known. This much, however, is certain, that when every gallon

of the available water supply is economically used, vast areas of rich farming lands will be unreclaimed for lack of water.

26. Waste of Water Due to Seepage and Other Causes.—The largest loss of irrigation water is due to the well-nigh universal practice of conducting it in earthen ditches. In 1910 the census enumerators reported 81,837 main and lateral ditches aggregating 125,591 miles in length. At that time probably less than 4 per cent. of the total number was lined or otherwise made impervious, thus leaving fully 120,000 miles of earthen channels. The loss of water in such channels may be grouped under leaks, evaporation and seepage. The first is due to poor workmanship or carelessness in operation or both and can be readily remedied. The second is small in comparison to the volume carried and on an average represents less than one-fourth of 1 per cent. of the flow, while the third is the main source of waste.

SEEPAGE LOSSES.—Opinions differ as to the relative merits of the two methods of expressing seepage losses in canals. One method expresses the loss per mile in the percentage of flow of the canal while the other expresses the loss in 24 hours in terms of cubic feet per square foot of wetted area. Both of these methods have their merits. The former gives one a ready grasp of the efficiency of a canal in a general way while the latter permits a more detailed estimate of the loss which may be expected from a given section of a canal when the conditions existing in it have been carefully studied. However, seepage losses from canals are governed by many variable and interdependent conditions, the combined influence of which makes it very difficult, if not altogether impracticable, to reduce to a mathematical formula. The writer is convinced that no refinement of calculation for estimating seepage losses in proposed canals is warranted at this time without considerable data directly applicable to individual conditions and even when this is obtainable the accuracy of the estimate will depend largely upon the skill as well as upon the experience and judgment of the estimator.

It is not within the scope of this publication to include a detailed discussion of the various factors influencing seepage, but in order to form a reliable estimate of the loss by seepage from a proposed canal, the principal factors should be carefully considered. Briefly these are:

1. Size and shape of grains and general character of materials.
2. Capillarity and gravitation.
3. The gradual deposition of silt.
4. Depth of water over the wetted perimeter.
5. The relation which the wetted perimeter of the canal bears to the other hydraulic elements.
6. Velocity of water in canal.
7. Inflow of seepage water.
8. Temperature of the soil and the water.

Table No. 19 shows the close relation existing between the unit loss as expressed in percentage of flow and the size of a canal. It has been compiled from data obtained from various sources which have been published in Bull. 126, U. S. Department of Agriculture, by the author. It is interesting to note the fairly constant decrease in the average loss in per cent. per mile as the capacity increases.

TABLE No. 19

Capacity of canal, second-feet	Number of tests	Average loss per mile, per cent.
Less than 1	16	25.7
1 to 5	37	20.2
5 to 10	30	11.7
10 to 25	49	12.1
25 to 50	48	5.5
50 to 75	31	4.3
75 to 100	26	2.7
100 to 200	45	1.8
200 to 800	27	1.2
800 and over	14	1.0

PREVENTION OF SEEPAGE LOSSES.—Seepage losses in porous channels may be greatly lessened by a lining of impervious material, such as clay or fine silt. Sometimes the beds of such channels contain more or less fine material mixed with the coarse and puddling may then be used to advantage. Puddling can best be done by making use of the canal after being moistened as a temporary feeding ground for sheep or goats. Whenever the material is too coarse to puddle, good puddling material may be hauled and spread over the surface of the canal. It is then moistened and tamped or puddled by the feet of domestic animals. After securing a clay lining in this manner it is well to ram coarse gravel into the surface, thereby making a clay concrete.

In all irrigation channels except those subject to erosion, a

gradual sedimentation takes place which renders them more impervious with age. Whenever water of silt-laden streams is run through canals the bottom soon becomes quite impervious necessitating frequent removal by cleaning. In fact the discharge of all streams subject to floods carries during periods of high water more or less silt, a part of which is deposited in the artificial channels and tends to make them water-tight.

A coating of heavy petroleum oil containing a large percentage of asphaltum was applied to a few canals in California at the rate of 2 to 3 gallons per square yard but the results of the experiments have not justified the extensive use of petroleum for this purpose.

At a time when lumber was cheap and Portland cement expensive it was common practice to line the weak and leaky beds of canals with lumber in the form of flumes. The short life of wood, particularly when in contact with earth, the high cost of maintenance, the rapid increase in the price of lumber and the corresponding decrease in the price of cement have all tended to lessen the use of wooden linings.

Concrete lining is now regarded as the best and as a rule the most economical lining to use in the prevention of seepage losses in irrigation ditches and canals. A large amount of concrete lining has been laid during the past 5 years and plans are under way for still larger investments in the future for this class of construction. The cost of concrete lining varies with the thickness, cost of materials, transportation charges and other factors. Generally the highest cost does not exceed 15 cents per square foot of surface lined, the lowest 5 cents and the mean 10 cents per square foot. The methods followed in lining farm ditches are given elsewhere.

A Flat Rate Per Acre Causes Waste.—In the most common form of water right contract between the owners of a canal system and the water users, the former agree to deliver a fixed quantity of water for a definite area of land. This ratio between a unit of water and a certain number of acres of land is known as the duty of water and is usually determined while the land is in its raw state and before the real needs of soil and crops as regards water have been ascertained. As a result of a random guess at the average duty over large tracts, some water users receive under their contracts more water than they can use economically, while

others may receive too little. The farmers have no incentive to economize in the use of water since their payments are based on a flat rate per acre. More than this, the combined efforts of the latter class are usually exerted in inducing the company to increase the general average duty.

Wherever it is practicable, irrigation water should be measured out to users in the same way that water for domestic purposes is metered out to consumers and let each pay for what he gets. Experiments have repeatedly shown that where water is delivered under a quantity rate, much less is used at no sacrifice to the yields of crops.

If the quantity rate per acre can not be adopted, it is usually feasible to form such a combination of the two methods as will serve the same purpose. In this combined method a minimum quantity of water per acre must be paid for by all users but to those who use more an additional charge is made for all excess. This method has been in vogue for years in the Imperial Valley, California, and has resulted in saving annually enormous quantities of water. Each water user is obliged to pay 50 cents for 1 acre-foot of water for each share of stock which he owns whether he uses the water or not. If he desires more water during any 1 year he has the privilege of purchasing it at the same price providing the total quantity does not exceed 4 acre-feet per share.

Continuous Delivery Wastes Water.—A continuous flow during the irrigation season may be delivered to large farms with only normal waste but in the case of small or medium-sized farms rotation should be practised in the interests of economy. The needs of the average crop for water vary greatly between seed time and harvest and a water-right contract which calls for a continuous delivery of a fixed volume of water from early spring to late fall is not only wrong in principle but wasteful of water. Instead of a continuous flow water contracts might better provide for the delivery at stated periods during each season of a definite quantity of water preferably expressed in acre-feet per acre. In the case of stored water, well water, or other constant sources of supply, the delivery might be made on demand of the user after due notification. A system of this kind would insure the delivery to the farmer of the proper amount of water at the right time.

Other Losses of Water.—The waste of water caused by evapo-

ration from irrigated fields, deep percolation, uneven distribution, poorly prepared fields, imperfect methods of application and unskillful use, will be treated under other headings.

27. Measurement of Water.—The necessity for measuring the water delivered to irrigators is now generally recognized throughout the arid region. While many irrigation enterprises still do without such measurements, the increasing value of water and the gradual establishment of the principle that irrigators should pay for the quantity of water used rather than for the number of acres irrigated are forcing measurements on the well-managed systems. Above all, wise farm management requires that irrigators should know by actual measurement whether they are receiving the water for which they are paying from 50 cents to $20 or more per acre-foot.

The measurement of water is a large subject. To treat it fully would require a volume in itself. The parts of the subject herein considered will, therefore, be limited to a brief presentation of those features which concern the irrigator and more particularly the devices and methods which he can employ in the purchase, delivery and use of water.

Units of Measure.—A number of standard units are used in the measurement of water. Other units and terms more indefinite in character are likewise in common use in certain localities and both kinds are herein defined.

(1) *Cubic Foot per Second.*—This standard unit, usually abbreviated to second-foot in America and to cusec in British India, represents the quantity of water flowing through a flume or other channel 1 foot wide and 1 foot deep with a mean velocity of 1 foot per second of time.

(2) *Acre-foot.*—As the term implies, an acre-foot is the volume which will cover 1 acre 1 foot in depth and is equivalent to 43,560 cubic feet. An acre-inch is one-twelfth of an acre-foot.

(3) *U. S. Gallon.*—The U. S. gallon contains 231 cubic inches.

The three units just described are standard in this country but those which follow vary with the state or locality.

(4) *Miner's Inch.*—This unit represents the quantity of water which will flow through an orifice 1 square inch in area under a given head of water. Since the head varies with the prevailing custom of different localities, the miner's inch likewise varies.

(5) *Head of Water.*—The quantity of water which is turned into a farmer's supply ditch is usually termed a head. The same term is used to designate the quantity used to irrigate a field. While the head of water is, as a rule, quite uniform over any given canal system it varies between wide limits among systems and states. In Utah a head of water is called an "irrigating stream."

(6) *An Irrigation.*—Equally indefinite is the term "irrigation" when used to represent the quantity of water applied to land at any one time. A light irrigation may not exceed 2 acre-inches per acre, whereas a heavy irrigation often exceeds 6 acre-inches per acre.

UNIT EQUIVALENTS.—In converting from one unit to another the volumes carried in ditches, stored in reservoirs, pumped from wells or spread over the land, the following table of equivalents may be found convenient:

1 cubic foot equals 7.48 gallons.
1 cubic foot of water weighs 62 1/2 pounds.
1 second-foot equals about 1 acre-inch per hour.
1 second-foot equals 1.983 acre-feet per day.
1 second-foot equals 448.8 gallons per minute.
1 second-foot equals 646,272 gallons per day.
1 acre-foot equals 43,560 cubic feet, equals 325,850 gals.
1 acre-inch equals 3630 cubic feet, equals 27,154 gallons.
50 miner's inches equal 1 second-foot in So. California, Idaho, Kansas, New Mexico, North Dakota, South Dakota, Nebraska and Utah.
40 miner's inches equal 1 second-foot in Central California, Arizona, Montana and Oregon.
38.4 miner's inches equal 1 second-foot in Colorado.

VOLUMETRIC MEASUREMENT.—Springs, ditches or small streams may be diverted into a vessel of known capacity and the discharge determined by noting the time required to fill the vessel. Larger flows may be diverted into tanks or reservoirs and measured by ascertaining the cubical contents of that part of the tank or reservoir which is either filled or emptied in a given time.

WEIRS.—The weir, Fig. 51, is one of the most common devices for the measurement of farm water supplies. It is accurate, cheap and easy to install. Conditions, however, are frequently encountered which prevent its use or lessen its efficiency. It is not a suitable device to measure the water of silt-laden streams owing to the rapid deposit of silt on the up-stream side of the weir. In other cases the grade of the ditch may be too flat to

FIG. A.—Downstream view of trapezoidal wire in use.

FIG. B.—Upstream view showing measurement being taken.

(*Facing page* 117.)

PLATE V

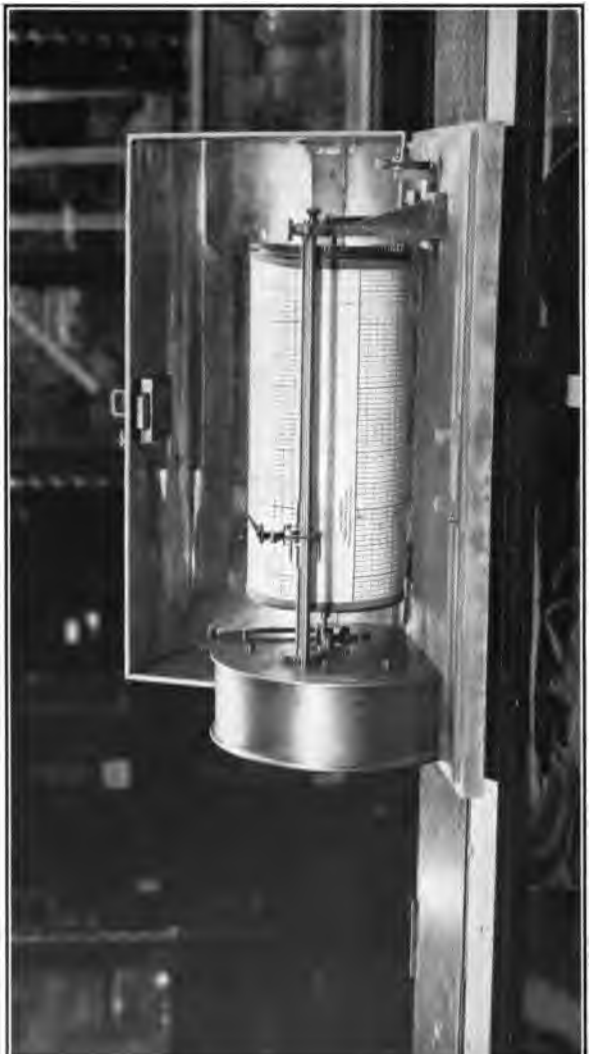

FIG. C.—Automatic water register.

permit of the necessary fall of water from the notch. Even under the most favorable conditions it is liable to become defective and give inaccurate results.

There are three types of farmers' weirs, rectangular, trapezoidal, and triangular, depending on the form of weir notch. In measuring water accurately by the use of any one of these types, it is desirable to reduce the velocity of water to a minimum as it approaches the weir. To accomplish this a small pond is formed on the upstream side of the weir. This can be done readily and

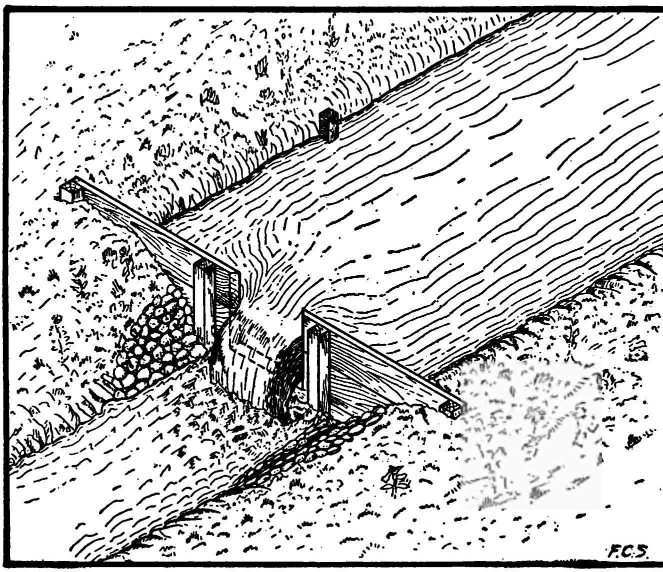

FIG. 51.—Rectangular weir showing pond.

cheaply in earth as may be seen from Plate V, Figs. A and B. An automatic water register (Plate V, Fig. C) is useful for recording the height of water flowing over the weir.

Where a slight error in measuring water is permissible the weir pond may be reduced in area and a corresponding reduction made in the dimensions of the weir box. This change will be apt to cause the water to approach the weir with some velocity but if this velocity does not exceed 0.5 foot per second the results of the measurement as given in Table 20 for Cipolletti weirs are likely to be sufficiently accurate for farm supplies.

Discharge over Cipolletti Weirs

Head of water		1-foot weir		2-foot weir		3-foot weir	
Feet	Inches	Cubic feet per second	Gallons per minute	Cubic feet per second	Gallons per minute	Cubic feet per second	Gallons per minute
0.11	1 3/8	0.123	55.3	0.25	112.4	0.37	161.2
0.12	1/2	0.140	63.0	0.28	125.9	0.42	188.8
0.13	9/16	0.158	71.0	0.32	143.8	0.47	211.2
0.14	5/8	0.176	79.2	0.35	157.3	0.53	238.2
0.15	3/4	0.196	88.1	0.39	175.3	0.59	265.0
0.16	1 7/8	0.216	97.2	0.43	193.3	0.65	292.1
0.17	2	0.236	106.1	0.47	211.2	0.71	319.0
0.18	1/8	0.257	115.5	0.51	229.1	0.77	346.0
0.19	1/4	0.279	125.5	0.56	252.0	0.84	377.5
0.20	3/8	0.301	135.2	0.60	269.5	0.90	404.0
0.21	2 1/2	0.324	145.5	0.65	292.1	0.97	436.0
0.22	5/8	0.347	156.0	0.69	310.0	1.04	468.0
0.23	3/4	0.371	166.8	0.74	332.5	1.11	499.0
0.24	7/8	0.396	178.0	0.79	355.0	1.19	535.0
0.25	3	0.421	189.1	0.84	377.5	1.26	567.0
0.26	3 1/8	0.446	200.5	0.89	400.0	1.34	602.5
0.27	1/4	0.472	212.0	0.94	422.0	1.42	638.0
0.28	3/8	0.499	224.5	1.00	450.0	1.50	674.0
0.29	1/2	0.526	236.5	1.05	472.0	1.59	711.0
0.30	5/8	0.553	249.0	1.11	499.0	1.66	746.0
0.31	3 3/4	0.581	261.1	1.16	522.0	1.74	782.0
0.32	7/8	0.609	274.0	1.22	548.0	1.83	823.0
0.33	4	0.638	287.0	1.28	576.0	1.91	858.0
0.34	1/8	0.667	300.0	1.33	598.0	2.00	899.0
0.35	1/4	0.697	313.0	1.39	625.0	2.09	940.0
0.36	4 3/8	0.727	327.0	1.45	652.0	2.18	980.0
0.37	1/2	0.758	341.0	1.52	683.0	2.27	1020.0
0.38	9/16	0.789	354.5	1.58	711.0	2.37	1065.0
0.39	5/8	0.820	368.7	1.64	737.0	2.46	1106.0
0.40	3/4	0.852	383.0	1.70	764.0	2.56	1151.0
0.41	4 7/8	0.884	397.0	1.77	796.0	2.65	1191.0
0.42	5	0.916	412.0	1.83	822.0	2.75	1238.0
0.43	1/8	0.949	426.0	1.90	854.0	2.85	1282.0
0.44	1/4	0.983	442.0	1.97	885.0	2.95	1326.0
0.45	3/8	1.016	455.5	2.03	912.0	3.03	1370.0

DISCHARGE OVER CIPOLLETTI WEIRS.—*Continued*

Head of water		1-foot weir		2-foot weir		3-foot weir	
Feet	Inches	Cubic feet per second	Gallons per minute	Cubic feet per second	Gallons per minute	Cubic feet per second	Gallons per minute
0.46	5 1/2	1.050	472.0	2.10	944.0	3.15	1412.0
0.47	5/8	1.085	487.5	2.17	976.0	3.25	1460.0
0.48	3/4	1.120	504.0	2.24	1008.0	3.36	1511.0
0.49	7/8	1.155	519.0	2.31	1038.0	3.46	1555.0
0.50	6	1.190	535.0	2.38	1070.0	3.57	1605.0
0.51	1/8	....	....	2.45	1101.0	3.68	1655.0
0.52	1/4	....	....	2.52	1132.0	3.79	1695.0
0.53	3/8	....	....	2.60	1169.0	3.90	1753.0
0.54	1/2	....	....	2.67	1200.0	4.01	1800.0
0.55	5/8	....	....	2.75	1235.0	4.12	1850.0
0.56	6 3/4	....	....	2.82	1268.0	4.23	1905.0
0.57	7/8	....	....	2.90	1303.0	4.35	1955.0
0.58	7	....	....	2.97	1335.0	4.46	2005.0
0.59	1/8	....	....	3.05	1371.0	4.58	2060.0
0.60	1/4	....	....	3.13	1408.0	4.69	2109.0
0.61	7 3/8	....	....	3.21	1441.0	4.81	2160.0
0.62	1/2	....	....	3.29	1480.0	4.93	2220.0
0.63	9/16	....	....	3.37	1515.0	5.05	2270.0
0.64	5/8	....	....	3.45	1550.0	5.17	2322.0
0.65	3/4	....	....	3.53	1587.0	5.29	2380.0
0.66	7 7/8	....	....	3.61	1622.0	5.42	2435.0
0.67	8	....	....	3.69	1659.0	5.54	2490.0
0.68	1/8	....	....	3.78	1700.0	5.66	2545.0
0.69	1/4	....	....	3.86	1735.0	5.79	2602.0
0.70	3/8	....	....	3.94	1771.0	5.92	2660.0
0.71	8 1/2	....	....	4.03	1815.0	6.04	2715.0
0.72	5/8	....	....	4.11	1850.0	6.17	2771.0
0.73	3/4	....	....	4.20	1888.0	6.30	2830.0
0.74	7/8	....	....	4.29	1930.0	6.43	2892.0
0.75	9	....	....	4.37	1965.0	6.56	2850.0

THE MINER'S INCH.—This method of measuring water was in common use in the West during the early mining period and under the conditions which then prevailed it was probably the best that could be devised. Since, however, it can be used only

to measure small streams, its use for this and other reasons has now become restricted to a few localities. Formerly each mining camp adopted its own standard "inch" but in more recent times nearly all the local standards have been combined into two kinds. In one of these the depth or head of water above the center of the opening is 4 inches and in the other it is 6 inches. The opening is usually 2 inches measured vertically. In the first-named kind, if the slide which controls the opening is pulled out so as to leave an opening 2 inches vertical by 25 inches horizontal, the discharge would be 50 miner's inches or an equivalent of 1 second-foot. In the last-named kind, owing to the greater head, if the slide is pulled out 20 inches so as to leave an opening 2 × 20 inches the discharge would be 40 miner's inches or an equivalent of 1 second-foot.

Submerged Orifice.—Water may be measured as it passes through a submerged opening in a gate or other structure by ascertaining the difference in elevation of the water surface on each side of the gate and adopting the proper coefficient of discharge through the opening. The former is readily obtained but the latter usually varies with each structure installed. In some types of submerged orifices an attempt is made to provide contraction on the bottom and sides of the opening but a contraction on the bottom soon fills with débris or sediment and this change in condition causes an over-registration of water.

Another frequent cause of error in this form of measuring device is due to the fact that the water may approach the opening with more or less velocity which likewise causes an over-registration.

A gate or box containing a submerged opening should be so planned and installed that there would be complete contraction on each side but no contraction on the bottom. The velocity of approach should also be eliminated as far as practicable and the whole device standardized, so as to cause the least change in conditions while in use. The discharge in second-feet may be computed from the equation $Q = CA\sqrt{2gh}$ where Q is the discharge in second-feet, C a constant ranging from 0.65 to 0.85, A the area of the orifice in square feet, g the acceleration of gravity in feet per second and h the head in feet.

This mode of measuring water used in irrigation is well adapted

to silt-laden water supplies and to localities with insufficient fall to justify the installation of weirs.

PROPORTIONAL DIVISION OF WATER.—In some states, notably Utah, not only the water carried by canals but also the discharge of the smaller streams is frequently allotted to the users in proportional parts of the entire flow. The basis of allotment is the number of shares of stock owned by each user, each share usually representing an acre of irrigable land. Since western streams and to a considerable extent western gravity canals are subject to wide fluctuations in the volumes carried, there is a

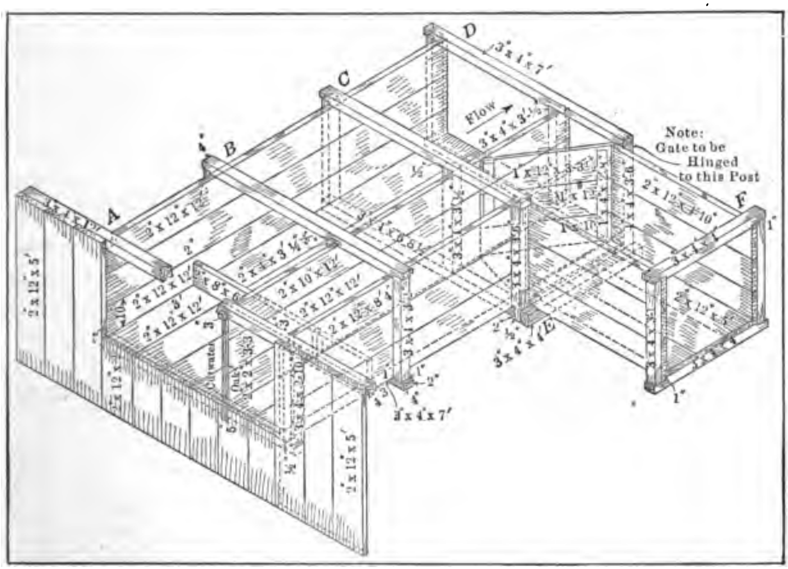

FIG. 52.—Design for proportional division box.

decided advantage in using this method. Its chief defect is due to a disregard of transmission losses which results in allotting too much water to the upper users of a system and too little to the lower users. An equitable apportionment of the available or net flow can be effected only by first deducting all losses due to transmission and this method requires the measurement rather than the proportioning of water.

The division box shown in Fig. 52[1] is based on the principle that

[1] Gate Structures for Irrigation Canals, by Fred C. Scobey. U. S. Department of Agriculture, Bul. 115.

water flows over a weir crest in volumes proportionate to its length providing certain conditions are complied with. These are (a) that the velocity of water above the weir and before it is influenced by it is quite low; (b) that the crest board be set far enough downstream in the flume so as to insure complete side contractions; (c) that the influence of backwater, if any, be uniform across the box and (d) that the crest be kept level.

The division of water by means of such boxes can best be described by an example. At a certain box delivering water to John Smith there are 84 shares including Smith's yet to be served. The width of the water channel is 60 inches which is reduced to a net width of 58 inches by deducting the width of the division board. Mr. Smith has 17 shares of stock and the width of the crest serving his ditch would therefore be found by the following proportion.

$$\frac{\text{Smith's crest in inches}}{58} = \frac{17}{84} = 10.75 \text{ inches}$$

Time-flow Method.—When a constant stream of water whose volume has been measured, is turned into a lateral ditch or pipe

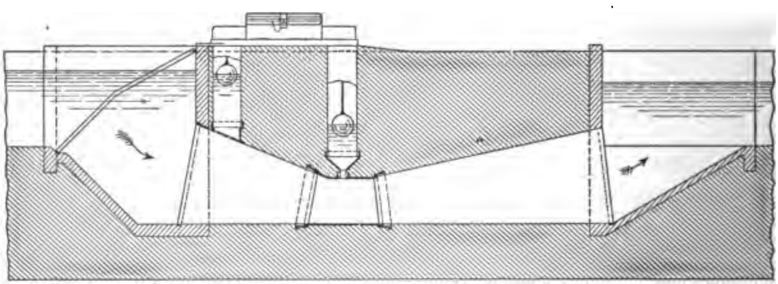

Fig. 53.—Venturi irrigation meter.

the simplest, cheapest and most accurate means of ascertaining the quantity delivered to each irrigator who uses it in turn is to keep a record of the time of flow to each. For lack of a better term the writer has called this the time-flow measurement. Where irrigation water is distributed under pressure through lateral pipes the special Venturi meter shown in Fig. 53 adapted to such conditions can be installed at the head of each lateral line. Where an open ditch is used the water entering the ditch can be measured by a weir or other device. In this way all deliveries

to users on the same lateral whether through a pipe or ditch can be made by the time-flow method.

Current Meter.—The current meter is a light portable device for measuring the rate of flow of water and consists of a screw propeller or cup-shaped wheel delicately mounted so that even a sluggish current will cause either to revolve. Each complete revolution of the meter or a fixed number of revolutions is noted by a click which is transmitted to the ear of the operator by a sounding tube or electrical connection.[1]

It is obvious that the faster the water flows the greater will be the number of revolutions of the meter and that each revolution will indicate a certain rate of flow in the water. The determination of this relation is called "rating the meter." If all meters of the same type revolved with the same ease and speed under similar conditions the manufacturer could ship with each new instrument the standard rating for that type. Numerous tests have shown, however, that no two meters behave exactly alike and for accurate work each has to be rated. A rating station has been established by the Bureau of Standards near Washington, D. C., and other stations are to be found in various parts of the West. The meter when being rated is attached by a rod to a car on a track and is held about 1 foot deep in still water. The car is then moved over a measured course at speeds ranging from 0.2 to 10 feet per second and over, an accurate record being kept of the time and the number of revolutions. From the results of a sufficient number of runs a table is computed which gives the rating of the meter within the range of the observations.

Water flowing under normal conditions in any ditch or canal has a relatively high velocity at the center and a slow velocity at either side and along the bottom. In order to obtain the average velocity it is necessary to determine the speed of the water at various points or in various sections. The usual practice is to select a suitable part of a straight channel having a smooth and uniform section in which the velocity of the water is slow rather than fast. An ideal velocity is about 2 feet per second. A plank or timber may be placed across the channel, Fig. 54, and the width

[1] For detailed description of current meter see River Discharge by Hoyt and Grover, John Wiley, New York, Publisher.

of the water-surface marked thereon in feet. Beginning at station zero as shown on the plank, ascertain the depth and mean velocity at station 0.25, and afterward at stations 1, 2, 3, etc. The depth in feet at stations 1, 2, 3, etc., multiplied by the mean velocity in feet per second, will give the flow for that particular station in cubic feet per second and the sum of all these products will represent the discharge of the ditch, with the exception of what flows through the small areas at each side. The small area between stations zero and 0.5 is considered as a triangle and its discharge computed. The fractional part of a station at the

FIG. 54.—Measuring a canal with current meter.

other edge of the water-surface is similarly treated, thus completing the total discharge.

In determining the mean velocity of any vertical section the integration method is recommended for small ditches and streams. This consists in moving the meter vertically from just below the surface of the water to the bottom of the ditch and back again to the surface, repeating the operation as often as necessary, taking note of the time by a stop-watch, and counting the revolutions of the meter in the entire period. In using this method, care should be exercised to move the meter very slowly and uniformly through the water, so as to secure the average of the different velocities in any vertical section.

SLOPE FORMULÆ.—In estimating the capacity of a dry ditch or one which is only partially filled, Kutter's formula may be used. In applying this formula it is advisable to determine the grade or fall of the ditch over at least 500 feet, and to apply the average grade thus found to a particular section. The sectional area, wetted perimeter, and coefficient of roughness for this section being next determined, the velocity and discharge may be computed from the known hydraulic elements.

AUSTRALIAN METER.—Most farmers prefer a measuring device which records the quantity of water delivered in some well-known unit. Such a meter has been devised by Mr. Dethridge, an engineer of Australia where it is in common use. It consists of a metal drum about 28 inches in diameter to which are attached V-shaped blades of the same material 10 inches in length. The drum carrying the blades revolves in a concrete flume about 30 inches wide, the middle portion of the bottom being concave to fit the revolving wheel. One-fourth of an inch clearance is allowed on sides and bottom. Each pocket between the projecting blades must be filled with water before the wheel revolves and the automatic recording device attached to the axle of the drum indicates the volume of water delivered.

Fig. A of Plate VI shows one of these meters being tested against a standard weir on the University farm at Davis, California. Fig. B of the same plate shows a meter of this type in operation in the State of Victoria, Australia.[1]

28. Evaporation from Water Surfaces.—Evaporation from water surfaces is of importance to the irrigation engineer in connection with the loss from reservoirs and to a very small degree in connection with the loss from canals. It is also of importance to the irrigation farmer because it gives some indication of the loss from the surface of irrigated soils discussed in Art. 29.

APPLIANCES USED.—Evaporation from water surfaces is usually ascertained by measuring the depth lost from evaporating pans or tanks freely exposed to the weather and set in the ground with the earth compactly replaced about them and with the rims of the pans or tanks protruding about 1 inch above the ground. It is generally customary to use round tanks made of galvanized sheet iron and varying in diameter from 2 to 8 feet and in depth

[1] See report for 1913, Western Canada Irrigation Association.

from 2 to 3 feet, a round tank 4 feet in diameter and 2.5 feet deep being suggested as a desirable standard.[1]

Additional equipment for ordinary observation consists of a hook gauge for measuring weekly or daily loss,[2] and a standard rain gauge for measuring precipitation between observations and refillings of the evaporation tank. For complete engineering observation there should be added a set of maximum and minimum thermometers and a standard psychrometer for ascertaining the dew point, and also an anemometer for ascertaining wind movement. The latter instruments are only needed when it is desired to apply observed data to situations considerably removed from the place of observation.[3] The entire equipment should be protected from stray animals by a low wire-mesh fence.

How Evaporation is Determined.—When feasible it is desirable to record evaporation not less frequently than once weekly and daily observations for short periods at intervals during the observational period are often desirable. When starting observations the tank should be filled to within 1 to 3 or 4 inches of the top, depending on the size of the tank and the prevalence of winds, these two factors determining possible slopping over the rim of the tank by wave action. During periods of possible excessive precipitation the water must be kept a safe distance below the rim, daily observations often being necessary to insure this result. A desirable plan is to fill the tank at each re-filling to the same depth. To the measured loss should be added at each observation the precipitation since the last observation. It

[1] Experiments by the U. S. Weather Bureau, reported in the Monthly Weather Review, February and July, 1910, pp. 307, 1133, indicate a sensible difference in the evaporation from vessels of different diameters, so that careful calculations of evaporation from observed data must necessarily take into account the sizes of vessels used in observations. As observed data regarding evaporation losses are often made general use of in engineering practice the need of a standard vessel is obvious.

[2] A recording evaporimeter for obtaining continuous records is a valuable addition to the equipment. For description of an evaporimeter used by the Irrigation Investigations of the U. S. Department of Agriculture, See U. S. D. A., O. E. S. Bul. No. 248.

[3] A much more elaborate equipment is used in observations and experiments designed to furnish data of wide scientific application. For description of such equipment see Monthly Weather Review, Feb. and Dec., 1910, pp. 307, 1133.

FIG. A.—Testing Australian meter against standard weir.

FIG. B.—Similar device used in Victoria, Australia.

(Facing page 125.)

is not necessary that the tank should be re-filled after each observation, yet a variation in the water level of more than 3 or 4 inches should not be permitted.

FACTORS GOVERNING EVAPORATION.—What determines the rate of evaporation from freely exposed water surfaces has been extensively studied, some of the most complete technical work done along this line in this country being that of Fitzgerald and the U. S. Weather Bureau.[1] The governing factor in evaporation is the temperature of the water, which is of course dependent on the temperature of the atmosphere immediately above,[2] evaporation taking place more rapidly when the surface water temperature is considerably above the dew point of the surrounding air. Other factors are air movement above the water surface, humidity, and possibly to some extent altitude. Air movement above a water surface increases evaporation to the extent that drier air is made to replace the air already charged with the escaping vapor from the water surface, for at any given temperature air is capable of holding only a definite amount of moisture, saturation occurring when that quantity is supplied. It has been found that while evaporation is greatly reduced during foggy weather, it does not altogether cease even with a saturated atmosphere provided there is air movement above. The effect of altitude merely in so far as concerns change in barometric pressure, is not yet fully established, although most observers credit it with exerting but little influence, and limited experiments of the U. S. Weather Bureau point to not greater evaporation at 4000 feet elevation, after correction for temperature, etc., than at sea level.

[1] For account of the work of Fitzgerald see Trans. Am. Soc. Civil Eng., Vol. XV, pp. 581 *et seq.* For account of investigations of U. S. Weather Bureau see Monthly Weather Review, Feb. and July, 1910, pp. 307, 1133. For additional miscellaneous references see among many others, Quart. Jr. Royal Met. Soc. (Eng.), Vol. XVIII, pp. 54 *et seq*, Bul. 45, Colo. Agr. Exp. Sta.; Eng. News. Apr. 6, 1905, p. 353; Sept. 19, 1907, p. 304; Aug. 13, 1908, p 163; Trans. Am. Soc. Civil Eng., Vol. LXXVI, p. 1516; U. S. Dept. Agr. O. E. S., Bul. 177, Eng. Rec., Feb. 12, 1910, p. 198, U. S. Dept. Agr. B. P. I., Bul. 188. For an extended bibliography on evaporation see Monthly Weather Review for 1908 and 1909.

[2] For results of experiments on the effect of water temperature on evaporation, especially in its relation to irrigation practice, see U. S. Dept. Agr. O. E. S.Buls. 177 and 248.

United States Evaporation Records.—Evaporation losses from small tanks or pans have been widely observed in the United States and table No. 21 gives the observed monthly and annual rates for various localities, records from evaporation tanks or pans situated on or near the ground chiefly being drawn from. The pans used in the observations reported have varied from 2 to 6 feet in diameter and have been mostly set into the ground.[1] Measurements of evaporation from large bodies of water have been very limited and are extremely difficult to make, owing largely to the uncertainties of underground increase or loss, as well as increase from surface run-off. Observations of the U. S. Weather Bureau at Salton Sea have added to the available data on the subject by showing that evaporation from large bodies of water is only between 60 and 70 per cent. of that observed from experimental tanks. In applying to reservoirs and other large bodies of water data obtained from small evaporating tanks or pans this correction should therefore be made. In estimating evaporation losses from reservoirs it should be further borne in mind that owing to the higher temperature of their water, shallow bodies evaporate more water than deep bodies, also, that thus far there has not been found an appreciable difference between the amount evaporated near the shore of lakes and reservoirs and at some distance from the shore.

29. Evaporation from Irrigated Soils.—Investigations to determine the rate of evaporation from irrigated soils have been carried on for a number of years by the Office of Experiment Stations, U. S. Department of Agriculture, under the supervision of the writer and summaries of the results obtained have been published in Buls. 177 and 248 of the Office. From these the following data are taken.

[1] The records given for Mecca and Lake Tahoe, Cal.; Deer Flat, Idaho; Fallon, Nev.; Carlsbad, N. M.; Ady, Oregon; and North Yakima, Washington, are the records of the U. S. Weather Bureau (Vol. LXIII, Eng. News, p. 694) and contain interpolations for from 3 to 7 months. The early records for California are from Physical Data and Statistics, 1886, and the later records are mainly from reports of Irrigation Investigations O. E. S., U. S. D. A. Other records are mainly from the reports and bulletins of the state experiment stations. Reports of the Irrigation Investigations and the various state experiment stations give a large number of part-season records.

TABLE No. 21

Average Annual and Monthly Observed Evaporation of Water from Small Experimental Tanks at Points in Western United States

(Inches)

State	Place of observation	Years recorded	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Arizona	Tucson	1892–94	2.76	3.00	4.54	6.95	9.06	10.96	10.10	8.87	8.24	6.39	4.11	2.45	77.43
Arizona	Yuma	1903–04	3.46	3.58	5.74	8.29	9.88	10.18	10.45	9.29	7.36	6.39	4.11	2.65	81.38
Arizona	Granite Reef	......	4.59	4.75	6.25	9.00	11.50	13.50	14.25	14.23	13.76	11.31	7.39	4.65	115.18
California	Chico	1904–05	0.295	1.135	2.435	3.88	6.21	7.925	9.17	8.615	6.16	3.955	2.46	1.235	53.475
California	Berkeley	1905	1.00	1.36	2.11	3.14	4.70	5.68	5.52	5.09	4.65	4.27	2.68	1.35	41.55
California	Tulare	1904–05	1.46	2.74	3.35	3.975	7.375	10.50	11.635	9.80	7.455	4.535	3.88	2.00	68.705
California	Pomona	1904–05	2.355	2.11	3.71	4.54	6.24	7.965	9.135	9.195	7.34	5.325	4.05	2.94	64.905
California	Calexico	1904–05	3.555	4.03	6.65	7.145	9.645	13.375	11.45	9.75	8.22	7.775	4.315	3.455	89.365
California	Kingsburg Bridge	1882–85	0.972	1.092	2.70	3.432	6.612	9.312	10.848	10.332	7.38	3.468	2.088	1.248	59.484
California	Lakeport	1902	0.85	0.30	1.55	2.35	3.70	5.15	7.40	4.95	4.40	1.85	0.45	0.45	33.40
California	Sweetwater Res.	1880–92–97	2.37	1.99	3.15	4.92	5.58	6.90	7.43	7.66	6.45	5.72	4.52	2.38	59.07
California	Arrowhead Res.	1895–97	0.33	0.53	1.03	4.12	4.30	6.42	6.32	5.62	4.69	3.62	1.24	0.93	46.30
California	Lake Tahoe	1909	1.75	1.75	1.75	2.00	3.00	4.25	6.19	7.08	6.22	3.60	2.62	2.00	42.21
California	Mecca	1909	2.92	5.00	8.07	10.87	12.72	14.23	15.21	13.22	10.29	8.17	4.13	2.98	107.81
Colorado	Ft. Collins	1887–1902	1.52	1.69	2.68	4.07	4.65	5.36	5.71	5.25	4.43	3.23	1.61	1.20	41.40
Colorado	Akron	4 years	....	....	....	5.43	6.91	8.53	9.36	8.61	6.85	....	....	....	....
Idaho	Deer Flat	1909	1.50	2.25	4.00	7.25	10.68	11.05	11.15	11.77	9.75	5.40	2.70	1.50	79.00
Kansas	Hays	5 years	....	....	....	6.85	7.26	8.85	9.09	8.82	6.96	....	....	....	....
Kansas	Garden City	4 years	....	....	....	7.61	8.76	10.14	10.00	9.35	7.69	....	....	....	....
Montana	Bozeman	1900–12	....	....	....	....	4.04	4.36	4.10	4.31	3.43	1.74	....	....	....
Nebraska	Dutch Flats	1909	1.75	1.75	3.00	4.50	6.25	8.05	10.95	9.39	7.44	5.59	4.00	3.00	65.67
Nebraska	North Platte	5 years	....	....	....	6.05	6.75	8.51	8.50	7.74	6.44	....	....	....	....
Nebraska	Lincoln	16 years	....	....	....	4.71	5.85	6.57	7.57	6.39	4.84	....	....	....	....
Nevada	Fallon	1909	1.75	1.75	2.25	3.25	5.25	7.86	9.86	8.70	5.15	3.35	2.50	2.00	53.65
New Mexico	Agri. College	1901–02	3.24	3.86	5.52	5.72	7.20	6.88	6.15	7.45	6.48	5.26	3.48	5.03	66.27
North Dakota	University	1905–11	....	....	....	....	3.87	4.47	5.82	4.59	3.46	1.93	....	....	....
North Dakota	Fargo	1902–06	....	....	....	....	5.04	5.80	7.72	7.74	3.55	....	....	....	....
Oregon	Ady	1909	0.50	1.25	3.57	6.64	7.15	6.99	8.01	9.21	6.13	2.50	1.00	0.50	53.45
South Dakota	Belle Fourche	1910–12	....	....	....	3.87	6.71	9.47	9.66	7.01	5.12	....	....	....	....
Texas	Amarillo	5 years	....	....	....	7.55	9.09	10.76	9.68	9.06	8.00	....	....	....	....
Texas	San Antonio	5 years	....	....	....	5.93	6.57	9.27	9.61	9.55	7.24	....	....	....	....
Utah	Ft. Douglas	1890–1902	....	....	....	3.40	4.30	5.20	7.20	6.40	5.00	2.20	1.40	....	....
Utah	Nephi	4 years	....	....	....	4.80	7.21	9.07	9.67	9.23	6.13	....	....	....	....
Washington	North Yakima	1909	1.75	2.50	6.25	7.91	8.36	8.90	10.74	9.41	5.51	3.15	2.00	1.50	67.98
Wyoming	Laramie	1901	....	....	....	....	5.05	6.18	9.19	5.78	5.89	....	....	....	....

The equipment (Fig. 55 and Plate VII) consisted of large double tanks of galvanized iron and suitable apparatus for weighing the soil in each vessel. The outer tanks were installed nearly level with the ground surface in a field or orchard and the annular space between the outer and inner tanks of each set was filled with water. In filling the inner tank with soil, care was taken to place it within the tank in its natural condition.

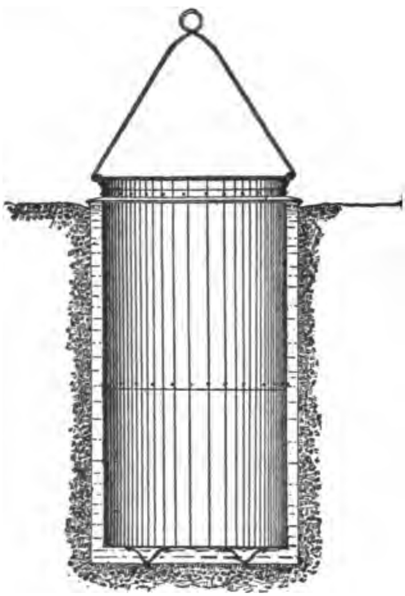

FIG. 55.—Design of tank used in evaporation experiments.

AMOUNT EVAPORATED.—The results of the experiments conducted at Riverside, California, showed that when the dry sandy loam of an orchard was irrigated by the furrow method, the average loss by evaporation during a subsequent period of 5 days was 15 per cent. of the water applied in irrigation.

In other experiments at the same place the loss by evaporation in 10 days after the surface had been irrigated by flooding ranged from 21 per cent. to 40 per cent. of the amount of water applied.

At Davis, California, soils which were irrigated by flooding lost in 21 days from 23 per cent. to 40 per cent. of the volume applied. At Reno, Nevada, similar losses during a like period were found to be 24 per cent. of the volume applied.

The investigations demonstrated that the same factors which influenced the rate of evaporation from a water surface (Art. 28) were also applicable to soils. In the case of soils, however, the main governing factor in the rate of evaporation is not the temperature of the soil and air, the movement of wind, or the humidity of the atmosphere but the percentage of moisture in the top layer of soil. This is illustrated in Fig. 56. It is further shown in Table 22 in which the weekly rates of evaporation from soil

and water surfaces may be compared under the same climatic conditions.

TABLE No. 22

Evaporation from Soil and Water

Kind of soil and percentage of free water	Mean temperature taken morning, noon and evening in degrees F.					Weekly evaporation	
	Air in shade	Soil in shade	Soil in sun	Moist soil	Surface of water	Soil, inches	Water, inches
Sandy loam—saturated...	71	76	95	83	77	4.75	1.88
Sandy loam—17.5.......	76	78	106	......	80	1.33	1.94
Sandy loam—11.9.......	76	78	106	......	80	1.13	1.94
Sandy loam— 8.9.......	76	78	108	......	80	0.88	1.94
Sandy loam— 4.8.......	76	78	108	......	80	0.25	1.94

The investigations likewise demonstrated that the loss by evaporation from newly irrigated soils, particularly when the entire surface is moistened was very great for the first few days after irrigation. One would expect this result from what was stated previously.

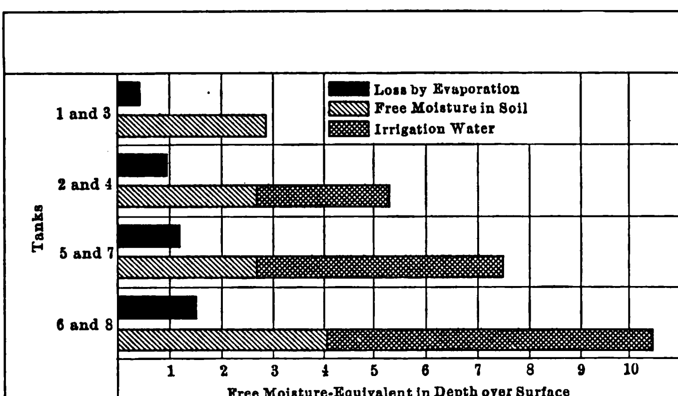

FIG. 56.—Diagram showing the initial amount of free moisture in the soil, the amount added, and the loss by evaporation, July 27 to Aug. 5, 1907, at Riverside, Cal.

PARTIAL PREVENTION OF EVAPORATION LOSSES.—In all crops the husbandman can materially lessen the amount of water lost by evaporation by properly preparing the surface of fields, adopting the right method of applying water and cultivating the soil at the right time. In following this course he will not only economize

in water but will increase the quantity and quality of the products raised. The foregoing applies in particular to all cultivated and deep-rooted crops and for these the following remedies for such losses may be applied.

(a) *Soil Mulches.*—At five stations throughout the arid region tanks (Fig. 55) containing soil were each irrigated to a depth of 6 inches. After the water had entirely disappeared from the soil surface, fine dry granular soil mulches were added as follows: Tanks 1 and 2, no mulch; tanks 3 and 4, a 3-inch layer; tanks

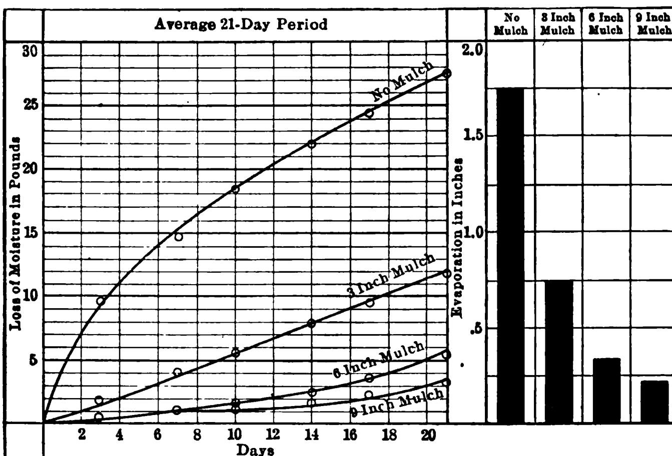

FIG. 57.—Average evaporation loses from tanks of soil protected by mulches of different depths during first 21 days after irrigation. Average loss at five stations.

5 and 6, a 6-inch layer; tanks 7 and 8, a 9-inch layer. Weighings were started immediately and continued semi-weekly for a period of 21 days. The average losses of water at the five stations are shown graphically in Fig. 57.

(*b*) *Cultivation.*—Similar equipment was used to determine the effect of cultivation in checking evaporation. The results of experiments conducted at six stations throughout the arid region with the accompanying meteorological data are given in Fig. 58. The average losses shown by the above are 2.13 inches from the uncultivated and 1.58 inches from the cultivated soils, being 35.5 and 26.3, respectively, of the total 6 inches used in irrigation. It is a significant fact that 51 per cent. of the loss

from the cultivated surface occurred in the first 3 days, that is, during the average period between irrigation and cultivation.

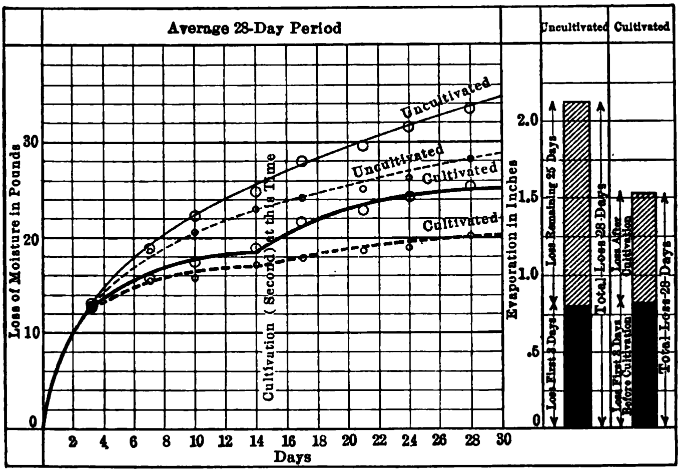

FIG. 58.—Average evaporation losses from cultivated and uncultivated tanks during first 28 days after irrigation. Average of losses at six stations.

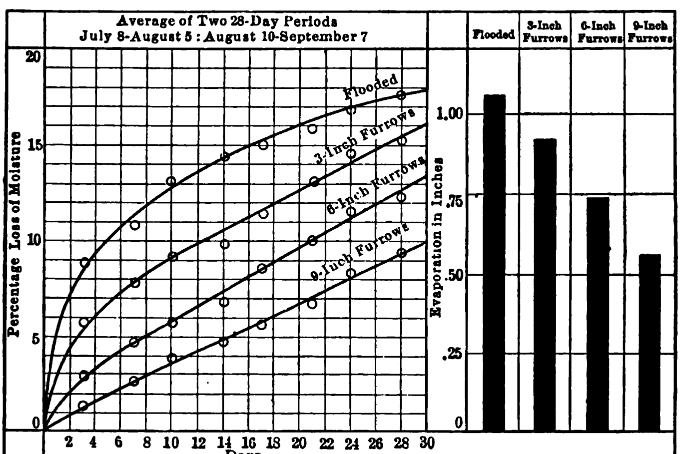

FIG. 59.—Average evaporation losses from tanks irrigated by flooding and with furrows of different depths at Reno, Nevada, July 8 to Aug. 5 and Aug. 10 to Sept. 7, 1909.

This emphasizes the necessity of early cultivation, especially in the heavy soils where the percolation of moisture through the soil is slow and the moisture content of the surface soil is high.

The observations also revealed a tendency in light sandy soils for the uncultivated surfaces to mulch themselves and after the first few days following the application of water the loss diminished very rapidly and in the end little advantage is shown in favor of cultivation. It not infrequently happens too, that the cultivation of soils containing a high percentage of free water increases rather than diminishes the loss by evaporation.

(c) *Shallow Versus Deep Furrows.*—Of late years in orchard irrigation in particular, where the furrow method is used, there has been a growing tendency toward fewer and deeper furrows with one heavy irrigation every 4 to 6 weeks rather than a larger number of shallow furrows with a light irrigation at short intervals. In shallow-rooted crops and in soils through which water percolates freely, the deep furrow is not to be recommended. On the other hand, where conditions pertaining to water supply, soils, and crops are favorable, the deep furrow affords a marked saving in the water used by checking evaporation. This is clearly brought out in Fig. 59 which presents graphically the summarized results of investigations conducted at Reno, Nevada.

TABLE No. 23

Summary of Temperature of Air, Soil, and Water, Humidity, Wind Velocity, Rainfall, Free Water in Soil, and Losses from Free-water Surface and from Cultivated and Uncultivated Tanks of the Several Stations

Stations	Number of trials	Temperatures				Humidity	Average wind velocity per hour	Total rainfall	Free water in soil	Evaporation from free-water surface	Loss from cultivated soils	Loss from uncultivated soils	Saved by cultivation
		Atmospheric	Cultivated soil	Uncultivated soil	Water								
		°F.	°F.	°F	°F.	P.ct.	Miles	In.	P.ct.	In.	In.	In.	P.ct.
Sunnyside, Wash...	1	65.2	71.3	74.3	70.9	....	.....	0.00	6.00	7.25	1.47	2.47	40.3
Davis, Cal.........	2	64.5	....	75.7	73.2	49.8	9.3	0.00	12.85	9.41	1.36	1.91	28.2
Reno, Nev.........	2	56.6	....	67.9	....	58.9	6.4	0.39	8.88	8.49	1.09	1.51	27.8
Caldwell, Idaho....	2	72.2	69.2	69.4	68.4	....	.....	0.14	6.21	9.81	1.91	2.42	21.0
Agricultural College, N. Mex.........	2	74.5	....	....	....	22.7	8.3	0.57	.....	11.13	1.37	1.59	13.8
Bozeman, Mont....	1	64.4	73.9	74.6	75.0	....	9.4	0.99	17.80	4.38	2.30	2.92	21.2
Average.........	...	66.2	71.5	72.4	72.9	43.8	8.4	0.35	10.35	8.41	1.58	2.14	26.4

30. The Duty of Water in Irrigation.—Duty of water in irrigation expresses the relation between a given quantity of water and the area which it serves. The water supply of the arid region

being limited in volume means must be taken to regulate its use. By the exercise of this control the flow of streams is apportioned to users of various kinds in accordance with a pre-determined duty. It therefore follows that the duty of water when fixed by competent authority affects communities and enterprises, as well as individuals and may affect states and nations.

All phases of this subject vitally concern the irrigator. He wishes to secure for his growing crops an adequate supply of water at the right time but in its use he may be governed wholly or in part by Federal statutes, State Laws, State regulations, court decisions or water right contracts which determine his right to divert and place limitations on the quantity of water which can be used for this purpose. It has therefore been considered best to preface this article with a brief outline of the broader aspects of the subject by discussing briefly the agencies and methods employed to place limitations on the quantity of water which can be used in irrigation.

1. *State Laws.*—The statutes of Idaho restrict the user to a maximum quantity of 1/50 of a second-foot per acre, but the courts of the state are empowered to grant more when necessary. This authority has been abused in a number of cases, since some decrees have granted as much as 1 second-foot for 10 acres. In the states of Wyoming, Nebraska, Oklahoma, New Mexico and South Dakota, the maximum limit is fixed by statute at 1/70 of a second-foot per acre, while in North Dakota it is 1/80 of a second-foot per acre. There is a similar limitation in Nevada but the unit adopted is in acre-feet per acre, 3 acre-feet being the maximum.

To the writer it seems unwise for any arid state to fix limitations of this kind. Outlined in another part of this article are some of the conditions which affect the duty of irrigation water. These conditions not only differ widely in different parts of the same state but change from year to year. The changes which time brings forth may be shown by citing a few cases. Some 25 years ago the irrigators of the Greeley district in northern Colorado were using a second-foot of water on 40 to 50 acres. In recent years the same quantity has served fully three times as much land with far better results when measured in crop yields. Again in the early nineties the farmers in the Bear River Valley

in northern Utah used a second-foot on 60 to 80 acres but during the past few years the average duty has been a second-foot for 120 acres. Furthermore, when the legislative assembly of Wyoming in 1891 limited the duty throughout that state to 1 second-foot for each 70 acres it was actuated by the best of motives. Such a duty was then high. Now it is too low and the state is handicapped by having apportioned so large a volume of its public waters on the limit fixed by statute.

2. *State Control.*—The control exercised by a state may affect the duty of water in several ways. In many of the western states the apportionment, measurement and distribution of the appropriated waters are in charge of state officers, who are required to distribute the flow of streams in accordance with adjudicated rights. It often happens that by the exercise of good judgment in the performance of this duty they can modify the defects or temper the harshness of court decisions. Sometimes the transfer of a little water for a short time from a superior to an inferior right may save a farmer's crops without inflicting any injury on his more fortunate neighbor who has a prior right. Such officers can be of so great service to the state in maintaining friendly relations among irrigators, in the prevention of waste of water, in the wise use of seepage and return waters, and in securing the largest possible benefits from all available sources of supply, that the trend of public opinion favors giving them large discretionary powers in the exercise of their public duties.

Another form of state control is exercised by state land boards in examining and approving the duty of water on lands under Carey Act projects. In Idaho, for example, the prevailing duty under such projects is 1 second-foot of water for each 80 acres of land, delivered at the head of the farmer's laterals.

State control is likewise exercised through special tribunals or water courts. In Wyoming the special tribunal is called the Board of Control and it is justly entitled to the highest praise for its efficiency. From the time this Board was created in 1890 and organized in 1891, up to January 1, 1914, it had adjudicated 12,500 rights to the use of water. These rights serve 1,510,000 acres. Considering the small number of its decisions that have been appealed no other court can show so good a record.

The writer is in favor of a special tribunal with state-wide

jurisdiction for the determination of water rights. He is likewise in favor of handing over to competent state officers the regulation of the water supply. Acting in accordance with these views, Mr. H. W. Grunsky and the writer, when called upon to advise the ministry of British Columbia on matters pertaining to irrigation, recommended, among other things, a form of water license for the Province. This form of final license is in force at this writing and contains the following "terms and conditions": (a) source of supply, (b) point of diversion, (c) the date from which the license shall take precedence, (d) the purpose for which the water is to be used, (e) the maximum quantity of water which may be used until lawfully altered, and the maximum quantity of water per annum which may be used on each acre actually irrigated in acre-feet, (f) the period of the year during which the water may be used, (g) the area and description of the land to which the water is appurtenant, (h) a concise description of the works, (i) a limitation of the water used per acre to that quantity which experience may hereafter determine to be necessary for the production of crops in the exercise of good husbandry, and (j) a reservation to the Province of the right to distribute water in rotation of time or otherwise for the purpose of securing the most economical use of water.

Some may regard these terms and conditions as unduly rigid and unfair to the irrigator. On the other hand, the belief is becoming quite general that the high value and scarcity of water and the demand which is being made on this natural resource will soon force the abandonment of lax laws and wasteful use affecting it.

3. *Court Decisions.*—Of the adjudicated rights, by far the largest number have been determined by district courts. Members of the legal profession generally favor this mode of procedure; and no valid objection can be raised to it, if only questions of law are involved. Needless to state, however, the proper determination of a right to the use of water resembles that of the survey and location of a piece of land. It is based on the results of investigations pertaining to water and land measurements, the carrying capacities of ditches, seepage and return waters, character of the soil, water requirements of crops and other physical facts of like nature. Considering the question

from this point of view it may well be doubted whether the ordinary law court is the best tribunal for such a purpose. In any event, grave mistakes have been made by such courts in the past. Some 20 years ago a part of the public waters of Colorado were adjudicated in a haphazard way with little or no effort to ascertain the physical facts. Many adjudications were based on the cross-sectional area of the ditch or canal without reference to its grade or the velocity of flow. In one case 33 second-feet of water were granted to 120 acres of land, and in another 31 second-feet to 200 acres. The owner of the ranch last referred to was recently offered $100,000 for the land and the water right, the latter being appraised at about $60,000.

It is but just to state that these decisions were rendered at a time when water possessed less value than it does today. Recent water decisions of the district courts are based on more accurate data, yet the tendency is still in the direction of granting a generous allowance, disregarding the public welfare and allowing too much latitude as to the period of time when the water can be used. Some of these weak features are brought out in the following references:

In 1909 the rights to the use of water on the West Gallatin valley in Montana were determined by a decree of the court. In this suit, 144 canals, providing water for 83,600 acres of land, were involved. In arriving at a decision some attempt at a rough classification of soils was made for the purpose of adjusting the amount of water decreed to the needs of the soil. In general, 1 miner's inch per acre (1/40 second-foot) was decreed to the more porous soils and 3/4 miner's inch to the silt and clay loams. These quantities were supplemented by allowances for seepage losses in the ditches and canals. These losses varied from less than 1 per cent. to 5 per cent. per mile. While the case was pending competent parties ascertained for the court the proper duty of water for both classes of soil. These were based on a 24-hour use of the water in each day. The judge, however, did not think it right to compel users to irrigate during the night and so based the decree on a 12-hour day by granting double the quantity of water required per acre. In this decision the seasonal time of use is not defined and in consequence

no provision is made for appropriating water from the same stream for storage or other purposes.

In a decision rendered in 1910 by Judge Kent of Arizona, the standard duty of water was fixed for much of the irrigated land in the Salt River Valley. The area affected by the decree embraced 179,970 acres and a constant flow of 48 miner's inches was allowed to each quarter section of land measured and delivered at the land. This is equivalent to 1 second-foot to each 133 1/3 acres or 5.42 acre-feet per acre per annum. A standard transmission loss due to seepage and evaporation was also adopted. This loss was placed at 1 per cent. of the flow per mile of main canal. Although of recent date, this decree has a far-reaching influence in that it has fixed for the past 3 years the duty of water for more than one-half of the irrigated lands of Arizona.

A peculiar feature of the decree is that the court retained jurisdiction of the case and the issues raised in the suit with a view to modifying any portion later. This reservation has great significance when applied to duty of water and seems to be the recognition of the fact that the water requirements of crops and soils change as conditions change. While a decision of this kind is quite arbitrary in character so long as it is in effect, yet the opportunity which it affords for modification encourages the fullest investigation of the amount of water actually required for different crops and soils. The results of investigations thus far made by the Office of Experiment Stations, U. S. Department of Agriculture, under the direction of P. E. Fuller, seem to point to the conclusion that 3 acre-feet per acre when economically applied will suffice for average crops and soils. If further investigation should confirm this view, it would justify an early modification of the present duty of water in the Salt River Valley.

4. *Water Right Contracts.*—In general it may be stated that court decisions in allotting water supplies favor the water users at the expense of the public while water right contracts favor the company at the expense of the water user. Whether justly or unjustly, water right contracts likewise exert a potent influence in restricting the quantity of water used in irrigation. While many companies and enterprises live up to their agreements,

some delivering to consumers more water than the contracts called for, others, through stress of circumstances, seek to overcome the defects of a short water supply or unsafe structures, or both, by the insertion of one-sided agreements in the contracts. Most contracts of this kind stipulate that the company agrees to furnish a fixed quantity of water which must be used on a definite area; and in case of water shortage at any time the amount available is to be prorated. Such provisions, when robbed of their legal phraseology, mean, as R. P. Teele of the U. S. Department of Agriculture states (Annual Report, O. E. S., 1908) "That the farmer takes what water he can get, for which he shall pay a flat rate per acre regardless of the quantity received."

Duty of water under contracts is expressed in various ways but measured in total volume for any one season it is seldom less than 1 acre-foot or more than 3 acre-feet per acre.

Units of Measurement.—The manner in which duty of water is expressed differs throughout the irrigated region. The unit of water may be the acre-foot, the second-foot, the miner's inch, or the U. S. Gallon per minute. In the rice belt where much of the water is pumped, duty is usually expressed in gallons per acre. Again, since the natural precipitation is measured in depth over the surface and is a factor to be reckoned with in connection with canal duty, the custom of using either the acre-foot or the acre-inch per acre to express duty has become quite general. In the more arid states where large quantities of ditch water are required the acre-foot is the better term, but in the humid region where small quantities are used as a supplemental supply during periods of droughts, the acre-inch is preferable. Another custom deserving of some recognition allows a certain quantity of water per month delivered as required rather than per season. The necessity for corporations and irrigation enterprises of all kinds obligating themselves to do this is shown by the monthly water requirements of the crops in Table 24.

Place of Measurement.—The duty of water may be measured (1) at the intake of the main canal, (2) at the intake of the lateral, or (3) at the margin of the farm. The results of measurements made at the first-named place are often spoken of as the gross duty, since they include all transmission losses

(Art. 26). Those obtained at the margins of fields are frequently designated the net duty, since all losses in transit are excluded.

CONDITIONS AFFECTING DUTY.—It has long been recognized that the amount of water required in irrigation differs widely on adjacent farms and in different localities and states. In briefly considering the causes of this the writer will not attempt to name all the conditions nor to designate the order in which they shall be presented.

(1) *Value of Water.*—Where water is plentiful and cheap less care is certain to be taken in its use and less money expended in facilities for its conveyance and application. This accounts for the large amount of water per acre which is used in parts of central California and the relatively small amounts used in southern California. There are, of course, exceptions to this rule. In Florida, for example, water is both abundant and cheap but irrigation water is exceptionally high on account of the methods employed in its distribution and application, the cost of which varies from $50 to $250 per acre.

(2) *Character of Soil and Subsoil.*—Porous soils, on account of the losses due to deep percolation, require much more water than retentive soils. This is illustrated in a marked degree by the use of water on the Reclamation Service project at Umatilla, Oregon. On the "sand hill" area north of the town of Hermiston in particular, the soil contains 60 to 90 per cent. of coarse sand and gravel with little fine sand and an almost negligible amount of silt and clay. The irrigation season extends from March 16 to October 16—210 days—during which period contracts call for the delivery to the land of 2.8 acre-feet of water per acre. In 1912 the actual average delivery to the entire project was 9.7 acre-feet per acre. On the more porous portions it is considered necessary to irrigate alfalfa three or four times for each cutting. One grower with 7 acres irrigated five times for the first crop, and six times for each of the following three cuttings, making 23 irrigations for the season.

(3) *Climate.*—The rain which falls during the crop-growing season and to a less extent the annual precipitation, have a marked effect on crop production and the use of irrigation water. In one sense all irrigation water is supplementary and the more

rain which is absorbed by the soil, the less is the need for artificial supplies. It is likewise true that much of the rain which falls during the period of growth is wasted. The light shower may invigorate certain crops but it seldom adds anything to the moisture content of the soil, being too soon dissipated in vapor. It may actually deprive the soil of moisture by breaking down the dust mulch. Not only rainfall but temperature, the prevalence of high, warm winds, the rate of evaporation, and other climatic factors exert an influence on duty of water. The traveler in proceeding north from Arizona and New Mexico into the Province of British Columbia can not but observe the heavy growth of timber which a light rainfall supports in the south-central part of this Province. On account of the heavy evaporation in the southwestern states, the same rainfall there produces only desert plants.

(4) *Proper Channels and Structures.*—In discussing the efficiency of irrigation water in Art. 25 the extent of the losses due to conducting water from place to place was pointed out. Until this waste is much reduced a high duty of water can not be secured. Furthermore, since the small ditches made by the farmer waste a higher percentage of water there is much need for reducing this loss by careful and efficient construction and in some cases even to the extent of making them water-tight. Much needless waste can likewise be saved by making shorter runs.

(5) *Preparation of Land.*—Coupled with proper facilities for the carriage and distribution of the head used there is also required the careful preparation of each field. To attempt to irrigate land which has a rough, uneven surface, is frequently the cause of much waste of water, extra labor, small yields and eventually damaged land. Not only thorough grading but thorough cultivation are essential.

(6) *Diversified Farming.*—Cereals usually require to be watered one or more times during the period from the time the plants cover the ground until the grain is well "headed out." This represents a short period and the farmer who raises only grain has no further use of irrigation water for the balance of that season. On the other hand, in rotating grain with such crops as alfalfa, roots and fruit, these latter require late water

and the use of the same flow is thus extended over a longer period and in consequence waters a larger acreage.

(7) *Time and Manner of Water Delivery.*—Water, as well as labor and time can be saved and an economical duty secured where conditions are favorable by using large quantities of water for short periods of time. Irrigators in the northern tier of states have been slow to abandon the continual use of small heads. While this method has its advantages for the man having a large farm and crude irrigation appliances, it will be found profitable on the whole to rotate the supply with one's neighbors. Watering crops is too important to be treated as a side issue. If one attempts to attend to other duties while water is running on his fields, only visiting the latter at long intervals, small yields are likely to result. It is better to see that the water is well distributed while it can be used. When the time of use has expired the headgate is closed and the water flows on to the neighboring farm.

(8) *Kind of Crops.*—The kind of crop, whether cultivated or uncultivated, and the length of season that it needs water, have a direct bearing on the amount of water required. Winter grains seem to require the least irrigation water because they mature early and are able to make good use of the winter precipitation. Spring grains are not usually planted until some of the winter precipitation has been evaporated. Cultivated crops, because of the moisture that can be saved by cultivation (Art. 29) require less water than uncultivated crops. Alfalfa, hay and pasture grasses grow luxuriantly through a long season and thus require the most water, it being found that such crops require about twice as much as grains.

(9) *Fertility of the Soil.*—Arid soils are deficient in vegetable matter and when this want is supplied by the right kind of rotation and by good farming generally, the soil becomes more retentive of moisture and a unit of water will supply a larger area than is possible when the soil is in a raw state. What is true of humus and nitrogen is also true of other fertilizers. Generally speaking, the richer the soil and the better it is tilled, the less the water requirements for any one crop.

(10) *Manner of Paying for Water.*—Paying for water by the season on an acreage basis tends to lower the efficiency of water.

As has been pointed out elsewhere the water user under such a contract is given no chance to reduce his water bill by the exercise of economy. On the other hand, the practice of paying only for what water one receives is invariably followed by an economical use.

(11) *Method of Applying Water.*—Faulty methods of application are liable to cause large losses in deep percolation, evaporation, run-off or in any or all of these combined.

(12) *Legal Restrictions.*—The effect of these on duty of water have already been considered in discussing the limitations imposed by statutory, regulatory and judicial means.

INVESTIGATING DUTY OF WATER.—A knowledge of the service or duty which water performs is necessary in all irrigated regions. This fact was early recognized in the development of the arid West. In 1892 the Colorado Experiment Station published a bulletin on this subject which gave the results of investigations made by Professor Carpenter. Two years later the writer began similar investigations. It was not, however, until Congress in 1898 appropriated money for irrigation investigations that a study of duty of water became general throughout the West. An urgent demand existed at that time for more information concerning the quantities of water used and required in irrigation. This information was needed by courts in determining water rights, by state officers in apportioning water supplies, by engineers in planning the capacities of canals and in estimating the areas of land which they would serve, by the managers of canal companies in drawing up water right contracts, and by those who used the water on their farms. Studies of this kind were continued for several years and the collected data proved of lasting benefit since they resulted in the framing of wise legislation and in the adoption of sound public policies in relation to water during a formative stage of irrigation development in this country. True, the results obtained have been criticised by agriculturists and others who contend that too little attention was paid to the character of the soil and subsoil and to the kind of crops grown. Such critics overlooked the fact that the investigations as first planned were intended to supply information regarding the legal, administrative and engineering features of irrigation rather than the agricultural. Besides, the funds

available were too small to permit a thorough study of the subject in all its phases. At that time it was infinitely better to ascertain the general average duty over 100,000 acres than to spend the same amount of money in more detailed studies on a 40-acre tract.

Both land and water measurements were made by men familiar with this class of work. The weir and rating flume were the most commonly used devices for measuring water. To secure a continuous record of flow, recording registers were imported from France until the demand for such instruments was pressing enough to induce American firms to make them. At first the work was quite generally confined to making a continuous measurement of the quantities of water which flowed through the intakes of the main canals but later the flow through laterals and farmers' ditches was measured. These measurements indicated a large transmission loss which took place between the main intake and the farmer's headgates, and efforts were made to ascertain the extent of these losses.

The writer was one of the first to apply different quantities of water to experimental plats in order to determine the effect of water on crop production. This work is still carried on in various parts of the West and bids fair to throw considerable light on the proper amount of water to apply to the different crops.

A plan of investigation which combined the plat and the large area was devised by Don H. Bark, irrigation engineer in charge of irrigation investigations in Idaho. Mr. Bark's plan consists in dividing a typical cropped field into three parts. The owner applies to one part in one or more irrigations that quantity of water which in his judgment, will produce the largest yield. Mr. Bark's assistant applies by the same method a larger amount to the second and a smaller amount to the third part. By means of weirs the amount of water applied as well as the run-off is carefully measured. The yield on each subdivision is determined at harvest time and by comparing the quantity of water applied with the yield, a fairly accurate conclusion may be drawn as to the proper duty of water for that soil and crop. A large number of such experiments have been financed in southern Idaho by funds obtained from the State

Land Board and the Office of Experiment Stations, U. S. Department of Agriculture and the results, which are summarized below, possess great value, not only to that state but to the West in general.

Results of Investigations.—The following table gives the average results obtained during the years 1910, 1911, and 1912 throughout southern Idaho. It shows that a project devoting about half its area to grain and other crops which require the least water, and the other half to alfalfa, clover and pasture, which need the most water, will require on an average about 2 acre-feet delivered to each acre exclusive of precipitation, which varied from 2 to 6 inches. Of this amount 0.82 per cent. was required in April, 16.08 per cent. in May, 31.67 per cent. in June, 32.25 per cent. in July, 16.38 per cent. in August and 2.79 per cent. in September.

Table No. 24

Summary of Depths of Water applied by Months to 168 Fields of Grain and Alfalfa on Medium Clay and Sandy Loam Soils in Idaho, Altitudes ranging from 2400 to 5000 Feet, Seasons 1910, 1911, 1912

Crop	Season	No. of plots	April		May, feet	June, feet	July, feet	Aug., feet	September		Total for season, feet
			1–15 feet	16–30 feet					1–15 feet	16–30 feet	
Grain.......	1910	39	.....	.....	0.320	0.6453	0.495	0.0954	......	.....	1.556
Alfalfa......	1910	17	0.053	0.018	0.531	0.7200	0.602	0.5510	0.0636	.....	2.540
Grain.......	1911	49	.....	.....	0.021	0.7170	0.428	0.0060	......	.....	1.172
Alfalfa......	1911	18	.....	0.025	0.525	0.3080	0.945	0.7500	0.1990	0.031	2.7813
Grain.......	1912	34	.....	.....	......	0.9140	0.650	0.0590	......	.....	1.623
Alfalfa......	1912	11	.....	.....	0.508	0.4430	0.697	0.4740	0.0376	.....	2.160
Average.....	....	.....	0.009	0.007	0.318	0.6245	0.636	0.323	0.050	0.005	1.972
Percentage of total....	....	.....	0.46	0.36	16.08	31.67	32.25	16.38	2.54	0.25	100.00

Some results of duty of water under typical canals throughout the arid regions are given in Table 25.

Similar results of duty of water under diversions from streams are given in Table 26.

Water Requirement of Crops.—The quantity of water required for various crops under field conditions has been treated in Arts. 35 to 36. The specific cases of water duty therein cited

TABLE No. 25

Name of canal	Location	Class of soil	Season	Length of season	No. of acres	Duty, ac. ft. per ac.
Riverside..........	Boise Valley, Idaho.	Clay loam	1911–12	Apr. 1–Oct. 31	3,004	8.31
Farmer's Coop......	Boise Valley, Idaho.	Clay loam	1911–12	Apr. 1–Oct. 31	7,160	5.13
Farmer's Union.....	Boise Valley, Idaho.	Clay loam	1911–12	Apr. 1–Oct. 31	6,993	5.60
Settlers............	Boise Valley, Idaho.	Clay loam	1911–12	Apr. 1–Oct. 31	6,440	2.95
Boise Valley........	Boise Valley, Idaho.	Gravelly	1911–12	Apr. 1–Oct. 31	751	3.15
Eureka No. 1.......	Boise Valley, Idaho.	Gravelly	1911–12	Apr. 1–Oct. 31	2,174	2.51
Pioneer............	Boise Valley, Idaho.	Gravelly	1911–12	Apr. 1–Oct. 31	1,137	5.72
Randall............	Rigby, Idaho	Gravelly	1912	Apr. 1–Oct. 31	3,255	6.87
Clark and Edwards..	Rigby, Idaho	Gravelly	1912	Apr. 1–Oct. 31	1,362	10.04
Ridenbaugh........	Boise Valley, Idaho.	Clay loam	1906–12	Apr. 1–Oct. 31	25,710	4.15
U. S. R. S. upper system.	Boise Valley, Idaho.	Clay loam	1912	Apr. 16–Oct. 31	45,664	2.88
So. Side Twin Falls	Twin Falls, Idaho.	Clay loam	1910–12	Apr. 1–Oct. 31	147,309	4.90
St. John...........	Malad, Idaho	Clay loam	1913	Apr. 25–Sept. 15	1,518	1.91
Larimer & Weld.....	N. Ft. Collins, Colo.	Clay loam	1910–12	May 3–Oct. 24	51,666	1.49
Cache la Poudre, No. 2.	Greeley, Colo.	Clay loam	1910–12	Apr. 21–Oct. 3	39,300	1.61
Loveland & Greeley	Loveland-Greeley, Colo.	Sandy loam	1910–12	Apr. 7–Nov. 14	19,330	1.11
Colorado	Arkansas Val.	....	1912	....	52,850	1.61
Amity..............	Arkansas Val.	....	1912	....	31,870	3.02
Logan-Hyde Park & Smithfield.	Logan, Utah	....	1909	June 1–Sept. 10	3,183	5.42
Logan & Richmond	Logan, Utah	....	1909	May 25–Aug. 31	3,375	5.16
Logan & Benson....	Logan, Utah	....	1909	June 13–Aug. 31	5,467	1.14
Bothwell or Bear River.	Garland, Utah	....	1902–05	Apr.1–Sept. 30	34,778	3.85
East Jordan........	So. Salt Lake, Utah.	Clay loam	1904–08 –12	May 1–Oct. 1	16,000	1.96
Grand Valley.......	Grand Jc., Colo.	Clay loam	1909–11	Apr. 1–Oct. 31	40,000	3.50
Wyo. Development Co.	Wheatland, Wyo.	Clay loam	1912	May 1–Sept. 30	33,500	2.93
Riverside Water Co.	Riverside, Cal.	....	1899–05	....	80,667	2.25
Imperial Water Co. Nos. 1, 4, 5, and 7.	Imperial Valley, Cal.	....	1905	....	120,000	2.04

TABLE NO. 26

Gross Duty of Water, by Streams

Stream	Canal	Approximate area irrigated	Water diverted per acre
		Acres	Acre-feet
Arizona: Salt River	Average of several	113,000	3.42
California:			
Santa Ana	Gage	7,000	2.16
Santa Clara	Average of several	5,160	2.00
Tule	Average of several	5,000	4.94
Tuolumne	Modesto	7,000	13.18
Tuolumne	Turlock	20,000	8.34
Cache Creek	Moore	7,000	3.15
Colorado:			
Arkansas	Amity	16,000	4.92
Arkansas	Lake	15,000	2.58
Grand	Grand Valley	22,000	4.11
Cache la Poudre	New Cache la Poudre	30,000	2.21
Big Thompson	Average of two	32,000	1.80
St. Vrain	Supply	7,000	1.79
Clear Creek	Average of three	53,000	1.37
South Platte	Average of several	67,000	2.90
Montana:			
Gallatin	Average of several	8,000	3.55
Yellowstone	Big Ditch	25,000	2.71
Bitterroot	Average of several	20,000	4.69
Nevada: Truckee	Orr Ditch	6,000	7.08
Nebraska:			
North Platte	Average of several	80,000	4.00
New Mexico: Pecos	Pecos	8,500	7.90
Utah:			
Big Cottonwood	Average of several	8,000	4.13
Logan	Average of two	6,000	4.08
Bear River	Bear River	17,000	4.84
Washington:			
Naches	Average of several	15,000	4.86
Yakima	Average of several	50,000	5.70
Wyoming:			
Laramie	Canal No. 2	6,500	3.72
Deer Creek	Average of several	....	10.40
Horseshoe	Average of several	....	9.75

may be regarded as typical for various crops under economic use. These figures do not, however, represent the actual water requirement for each crop since more or less water is wasted in

PLATE VII

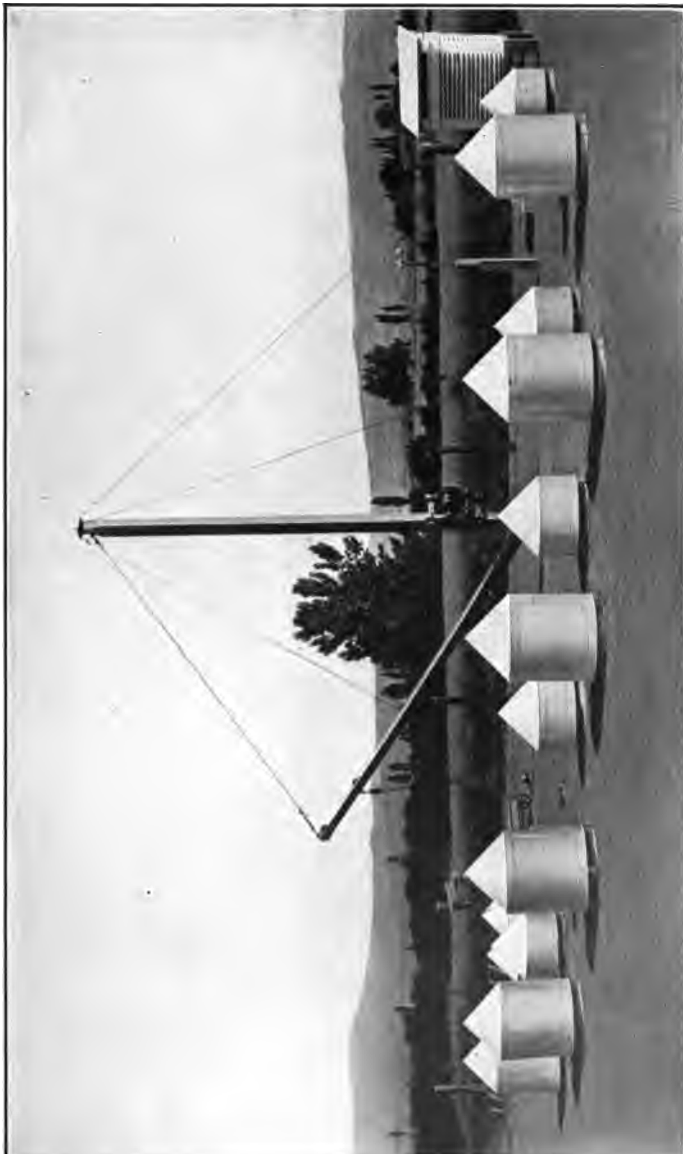

FIG. A.—Equipment used for determining the water requirements of crops.

(*Facing page 149.*)

PLATE VII

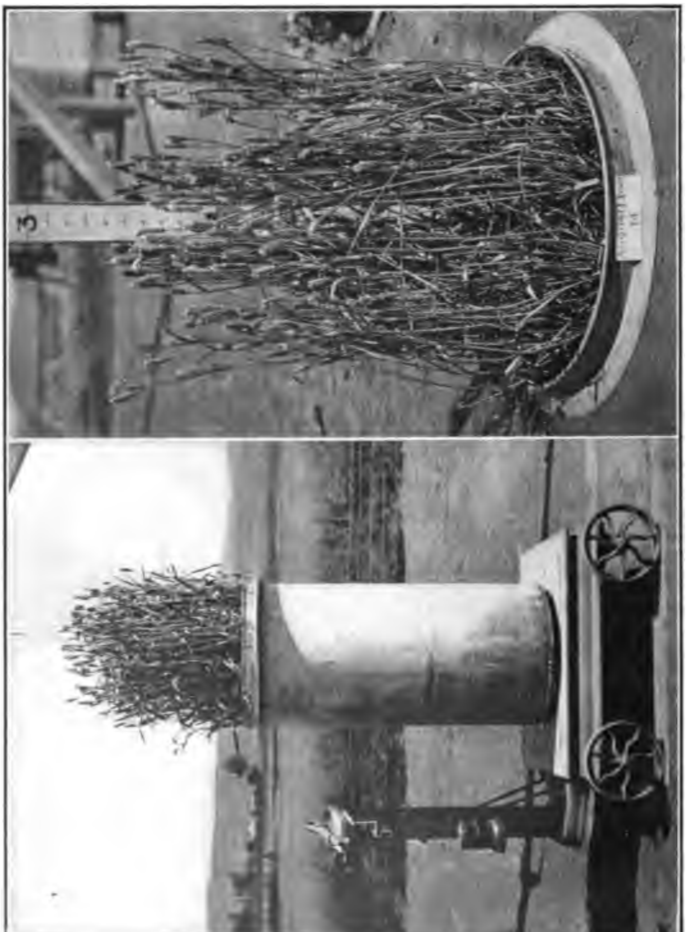

FIG. B. FIG. C.

FIGS. B and C.—Equipment used for determining the water requirements of crops.

applying it to fields. Investigators have attempted to eliminate this waste by growing plants in vessels and the results of their investigations are briefly summarized in the following table which is compiled in part from Buls. 284 and 285 by Briggs and Shantz of the Bureau of Plant Industry, U. S. Department of Agriculture.

In scanning the figures which represent in the table the ratio in pounds between the water absorbed and a pound of air-dried crop produced, one can not but note their incongruity. In many respects they do not seem to agree with the views of practical growers. Rye, for example, which requires little moisture according to the belief of many farmers, stands near the head of the list, the ratio averaging 724 in the experiments conducted at Akron, Colorado. Again, the average of experiments on red clover made in England, Germany and the State of Wisconsin is 354 pounds of water to a pound of dried clover hay. Judging from these results the water requirement of rye is more than double that of red clover.

While the results which have been assembled in the table can not be accepted as a safe guide to practise, yet they show that a beginning has been made in this important study. The work already done has brought into prominence the effect produced on the water requirement of standard crops by certain conditions of the soil in which the crops are grown. Among these may be mentioned the moisture content, temperature, fertility and kind of soil. The influence exerted by atmospheric conditions has likewise been studied as well as the demands of the plant for water at critical stages of its growth. What is urgently needed at this stage of progress is the standardization of the methods employed so that the results may be more readily and accurately compared. In devising such methods it is essential that the plants under test be grown as nearly as possible under natural conditions (Plate VII) in order that the farmer may know how much water is required for any given crop. This is especially needed for irrigation farming. The prevailing custom in irrigated districts as has been pointed out, is to measure the duty of water for crops at the headgate of the ditch or canal but the rapid increase in the value of water is drawing attention to a more economical method. In recent years more consideration has been given to

the actual needs of each crop for water and of basing the net duty thereon. If, for example, it is known that wheat averaging 40 bushels or 2400 pounds to the acre with the accompanying straw weighing 2900 pounds, requires 350 pounds of water to each pound of grain and straw, the net duty of water would be about 0.68 acre-foot per acre. To this minimum allowance should be added whatever loss is sustained in the carriage of the water, deep percolation, run-off and evaporation from the soil. Many good reasons might be given in favor of this method of determining duty of water in irrigation but until more definite knowledge is obtained concerning the actual water requirement of various crops under field conditions it can not be applied. Viewed from this standpoint that method of experimentation may be said to be best which approaches nearest to natural field conditions. In this connection the writer would recommend as the result of his experience in making such investigations, that the unit of soil used in the experiment be as large as practicable and that the vessel containing this unit be placed in the ground and water-jacketed. The first insures a near approach to field conditions and the second controls the temperature. It is a well-known fact that temperature and moisture are the two main conditions which cause the natural vegetation of one region to differ from that of another. Hence it follows that in conducting experiments of the kind under consideration the temperature of the soil in which the plants grow should be maintained nearly equal to that of the soil in the field. By making use of such water-jacketed vessels or tanks as are shown in Fig. 55 and placing these in the ground with their tops nearly level with the surface, the temperature of the soil within them is not only kept equal or nearly equal to that of the soil without, but wind, sunshine and rain exert a more natural influence on the plants under test.

31. Delivery of Water.—The final test of the success of every irrigation project is the quality of the service rendered to irrigators in the matter of water delivery. Adequate water de-

[1] In at least one western state, California, the state public service commission has authority, which is being freely exercised, to compel adequate water delivery service by public service corporations supplying water for irrigation.

livery service can be nothing less than the reasonably prompt giving to each irrigator the full share of water to which he is entitled and at such time and at such rate of flow as the crops to be

TABLE NO. 27

Water Requirement of Various Standard Crops

Crop	Location	Experimenter	Pounds water per pound of dry matter		
			Max.	Min.	Mean[1]
Wheat....	Germany........	Sorauer...........	708	....	708
	Germany........	Hellriegel.........	390	328	339
	Germany........	Von Seelhorst.....	333	....	333
	India............	Leather...........	544	....	544
	Akron, Colo......	Briggs & Shantz...	534	468	507
	England.........	Lawes............	235	....	235
	Logan, Utah.....	Widtsoe..........	489	427	458
	Davis, Cal.......	Fortier & Beckett..	359	286	326
	Bozeman, Mont..	Fortier & Gieseker.	334	226	271
	Reno, Nevada....	Fortier & Peterson.	395	309	360
Oats......	Germany........	Wollny...........	....	....	665
	Germany........	Sorauer...........	....	....	600
	Germany........	Hellriegel.........	464	339	401
	India............	Leather...........	....	....	469
	Wisconsin.......	King.............	526	502	514
	Akron, Colo......	Briggs & Shantz...	639	598	614
Barley....	England.........	Lawes............	262	258	260
	Germany........	Wollny...........	....	....	774
	Germany........	Sorauer...........	....	....	490
	Germany........	Hellriegel.........	366	263	297
	Germany........	Von Seelhorst.....	454	295	365
	India............	Leather...........	....	....	468
	Wisconsin.......	King.............	401	375	388
	Akron, Colo......	Briggs & Shantz...	544	527	539
Corn.....	Germany........	Wollny...........	....	....	233
	India............	Leather...........	....	....	337
	Wisconsin.......	King.............	390	305	348
	Akron, Colo.....	Briggs & Shantz...	420	319	369
Rye......	Germany........	Hellriegel.........	438	315	377
	Germany........	Von Seelhorst.....	700	343	469
	Akron, Colo.....	Briggs & Shantz...	....	....	724

[1] Under this column are given the average of all reliable and comparable tests.

TABLE No. 27

Water Requirement of Various Standard Crops.—*Continued*

Crop	Location	Experimenter	Pounds water per pound of dry matter		
			Max.	Min.	Mean
Peas	England	Lawes			235
	Germany	Wollny			416
	Germany	Hellriegel	353	231	292
	India	Leather			563
	Wisconsin	King			477
	Akron, Colo.	Briggs & Shantz			800
Potatoes	Germany	Von Seelhorst	294	268	281
	Wisconsin	King			423
	Akron, Colo.	Briggs & Shantz			448
Alfalfa,	Davis, Cal.	Fortier & Beckett			
1st. Yr.			1265	1005	1102
2nd. Yr.			971	522	761
	State College, N. M.		889	757	823
	Akron, Colo.	Briggs & Shantz			1068
Clover	England	Lawes			251
(red)	Germany	Hellriegel	363	297	330
	Wisconsin	King	564	398	481
Sugar	Logan, Utah	Widtsoe			497
beets	Akron, Colo.	Briggs & Shantz			377
Rice	India	Leather			811

irrigated require. If one crop is mainly irrigated there is generally little difficulty in arranging a satisfactory plan of water distribution and delivery, for in the main each irrigator is in a like position with all of his neighbors with reference to the quantity of water needed per acre and the interval between irrigations. But one-crop agriculture is not usual, except in districts that have highly specialized crops, so that the irrigation manager arranging a plan of water distribution and delivery ordinarily must arrange to supply water to diversified plantings scattered over the entire project. Some crops, like small fruits and shallow-rooting annual field crops, are usually quite sensitive to comparatively light drought, while others, as alfalfa and orchards on deep soil, are more elastic in their need for irrigation,

although even the latter are best served by regular waterings, and can not go without water beyond certain varying periods without serious damage. Recent investigations indicate that in some instances the character of the product, as well as the quantity, are influenced by the time of applying water.

RELATIONS OF SUPERINTENDENTS OR DITCH TENDERS AND IRRIGATORS.—Since the essential condition of a successful irrigation system is adequate water delivery service, it follows that those directly in charge of water delivery should be in close touch with the irrigators served and thoroughly understand their water requirements—how much water the different crops need at each irrigation, how often irrigation is essential in the case of different crops, how water is applied to the various soils and to the various crops with least waste and most efficiency. Both superintendents and ditch tenders should constantly bear in mind that an entire year of effort on the part of the farmer may be either wholly lost or very adversely affected by a failure in the water delivery service; also that the service that is acceptable to one irrigator may not be the service needed by another. In order that both ditch tenders and irrigators may throughly know their relations to each other, the plan of water delivery to be followed and the duties and rights of each should be made a part of the printed rules and regulations of the system and be in the hands of every ditch tender and every irrigator.

REGULATIONS GOVERNING WATER DELIVERY.—Every irrigation project is in some degree different from every other project and the necessary and proper regulations for each must necessarily be prepared with regard to the particular conditions present. Still there are certain principles of regulation that with some variation are desirable for any well-managed system and the most important of these have been outlined by Frank Adams, in charge of Irrigation Investigations of the Department of Agriculture in California in the following paragraphs.

(1) "The superintendent and the ditch tenders working under him should have sole control of all gates, checks, and turn-outs, and users should be prohibited from altering them without definite authority from the superintendent or ditch tender, of course excepting cases of emergency.

(2) "Every irrigator should be required to make written application

for any water wanted, on blanks furnished by the management, the application to be handed to the ditch tender or sent directly to the central office of the system a sufficient number of days—usually 1 to 3—prior to the time water is needed. This enables the superintendent and ditch tenders to make necessary arrangements for getting the required flow in the various laterals.

(3) "Irrigators should be given ample notice of the time water is to be delivered and should be held responsible for being ready to receive it at the time set.

(4) "During time of water delivery ditch tenders should, wherever practicable, be required to be within ready call of the irrigators receiving water. This is especially necessary where comparatively large irrigating heads are being delivered because it frequently happens that for one cause or other the delivery must be temporarily or prematurely stopped, in which case the ditch tender should be on hand to care for the water turned back.

(5) "It is desirable, but not always practicable, that water users should make all complaints in writing. In justice to the users the rules should require that all complaints filed in writing shall be promptly investigated by the superintendent.

(6) "The rules should require ditch tenders to keep careful record, on suitable forms furnished by the management, of all deliveries made, such record to state the time of beginning and ending of each delivery, the size of head furnished, the acreage irrigated, and the crop watered. On some systems it has been found desirable to require irrigators to give written receipts, preferably in the ditch-tenders' record books, for deliveries made.

(7) "Ditch tenders should be given authority in the rules to prevent all avoidable waste from the irrigable fields. Where water is repeatedly wasted through excessive application the ditch tenders should be required to report the fact in writing to the superintendent, regardless of whether this waste is depriving some other user of water. Excessive application of water is of general injury through causing the rise of ground water, and irrigators should at the start be taught that they are entitled to no more water than the crops being irrigated require.

(8) "The rules should require all farm ditches to be of proper capacity to carry without undue waste the water delivered. They should also require that they be kept in good repair throughout the delivery season.

(9) "Authority should be given in the rules for placing locks on all turn-out gates when this is found necessary.

(10) "The superintendent should be given full authority to discontinue water delivery to any irrigator who wilfully and repeatedly disregards the established regulations of the system.

(11) "It is usually desirable to establish a definite irrigating season within which water will be available. In such cases the limits of the irrigation season should be stated in the rules. This should not mean that where feasible water is not to be run at other times. Sometimes it is very desirable that irrigation should occur during the winter months which are never included in a regular irrigation season, and where desirable, this should be encouraged. In the Southwest some irrigation systems usually carry water for 10 or 12 months of each year.

(12) "The rules should specify the duties of ditch tenders in the matter of patrol and care of canal banks and structures, and also in the matter of reports to their superintendent and of their proper relations to irrigators."

PLAN OF WATER DELIVERY.—Attention has already been called to the necessity for adopting a plan of water distribution and delivery that will give water to each irrigator at the time and in the quantity required by the crops to be irrigated. While very large farms, as of a full section of land, can sometimes profitably use a continuous flow of water, it has become almost universally recognized that delivery by some plan of rotation is by far the best plan to follow and the only plan that is generally economical. It eliminates the wasteful use of small heads, there being much greater economy, within reasonable limits, in using a large enough head to get over land quickly than in using for a longer time such a small head as continuous flow would require.

The simplest plan of rotation delivery is one in which each irrigator may receive water during each run for a certain definite length of time for each acre irrigated, all delivery heads to be of equal quantity. The runs may be arranged to begin and end at such times as may be fixed during the season, the size of heads also being changed from time to time as the total supply available for delivery makes desirable. In this simple plan the various runs are usually not definitely scheduled at their beginning to show the time of delivery to each individual irrigator. Instead, as the runs proceed each irrigator is notified in advance as to the approximate time delivery may be expected, water being allowed to each until his farm is well watered or until delivery has continued for the apportioned time for each acre in the farm. Breaks or other interruptions merely delay the completion of the runs during which they occur. This plan of delivery is quite common

on large systems, especially in the earlier periods of their operation.

A more complete plan of rotation delivery, involving full seasonal schedules, by which each irrigator knows at the beginning of each season the hour and day when he will receive water during every run, is not uncommon on some of the older irrigating systems, and especially on some of the smaller systems, as in southern California, under which one crop or one system of plantings chiefly occur. For such a system a reasonably regular supply of water in the main canal is necessary, and, except on some of the smaller systems, this does not frequently occur. On the small southern California systems using this seasonal schedule plan water is usually delivered to each irrigator once every 30 days, or a one-half supply is delivered every 15 days, the last day in 31-day months not being counted in making up the schedules. On one large system in Utah a continuous flow of at least 2.1 second-feet is maintained in each consumer's lateral, these laterals having been laid out to permit of this, and each irrigator receives water at this rate 1 hour each week for each acre irrigated, the same schedule being followed substantially year after year.

The above-mentioned rotation plans, or modifications of them, are suited to systems delivering water on an acreage basis. But when water is paid for according to quantity received a different rotation plan is necessary, where rotation is followed. Paying for the quantity of water received results in a considerable variation in the quantity used per acre, both as between individual irrigators and during the season in the case of single irrigators. This makes regular individual delivery schedules impracticable but does not alter the desirability of rotating between the various parts of a system in order to do away with running less water in laterals than they are designed to carry economically. Even where water is paid for on an acreage basis this rotation between laterals, especially in times of shortage, is desirable for the same reason.

On some systems continuous flow to individuals, who in turn rotate to some extent between each other, constitutes another rotation plan. Sometimes, even when the main delivery schedule provides rotation between individuals, two or more of

these individuals carry the plan even further by rotating among themselves.

While delivery on demand sometimes goes with a modified plan of rotation, some systems are so arranged as to distributaries and crops grown that it is most satisfactory to have water continuously subject to demand in nearly every part of it. With an all-reservoir supply this is an excellent plan, no water needing to be turned into the distributaries unless previously called for. Where the demand for water is sufficiently even so that the needs and the supply can be balanced so closely in advance that practically no water is wasted, as is the case with some of the southern California systems irrigating citrus fruits, the plan becomes an almost ideal one, especially, as is the case with many of the southern California systems, when the water distribution on the farms is through underground pipes.

Possibly of equal importance with the plan of water delivery to be followed is the plan of charges to be made for the water delivered. Authorities are now almost a unit in holding that water should be charged for according to quantity delivered rather than according to acreage irrigated. Experience shows that a much higher duty of irrigation water is reached under the former of these two methods. In recent years there has gradually grown up the practice of making a flat acre charge for the first acre-foot or for the first 1.5 or 2 acre-feet delivered, with a quantity charge for water delivered in excess of that. This is an admirable principle if the quantity permitted under the flat acre rate is not made too large. The importance of this matter, however, is more fully discussed in Art. 26.

DELIVERY FORMS AND RECORDS.—Reference has already been made to the desirability of ditch tenders keeping accurate record of all deliveries of water to individual irrigators. In the earlier years of a project it is sometimes very difficult for those operating irrigation systems to find time to keep many records. A full record system of water distribution and delivery should, however, be begun at the earliest possible time. The essential records in this connection would cover (a) the daily flow in the main canal of the system and the daily amount available in reservoirs, (b) the daily diversions from the main canal into the principal laterals, (c) the daily deliveries to individuals, (d) a delivery

ledger account for each irrigator where the quantities delivered are charged for, and (e) ditch tender's diaries. Many private, cooperative, and district irrigation systems, and also the various projects of the United States Reclamation Service, have worked out very complete records and forms. For descriptions of these forms reference is made to Bul. 229 of the Office of Experiment Stations, U. S. Department of Agriculture by Frank Adams, and to the operation and maintenance manual of the Reclamation Service.

Delivery Force Required.—The first essential of a water delivery force in irrigation systems is, as previously pointed out, that it shall understand the needs of the water users. While it is almost always necessary that the ditch tenders charged with water delivery shall also patrol the canal system for breaks and make all ordinary repairs that can be attended to in connection with their other duties, their duties in connection with water delivery should be paramount to maintenance and on large systems at least their water delivery activities should be directed by a head water master not connected with the maintenance work of the system. The number of miles patroled per day by ditch tenders may vary from 5 or 6 to about 20. The average number of miles traveled on fifteen projects of the U. S. Reclamation Service is given by F. W. Hanna as 22.4, with the average number of users served daily per ditch tender as 26.2. An authority on systems in Montana gives 10 to 12 miles per day as the usual length of main canal patroled daily by each ditch tender, with 5 or 6 miles the length of section patroled on laterals while at the same time about fifteen private turn-outs being cared for. One large system in Wyoming employs one ditch tender to cover each 5 to 10 miles of main canal and all laterals leading from it. The average length of main canal and laterals served per ditch tender under four important systems in California is 11.7 miles. On one large system in Colorado it is 23.5 miles. On another in the same general section it is 13.3. On three large Utah systems it is 19.4 miles. These figures indicate a wide difference which is probably more apparent than real so far as pertains to service performed, owing to the different duties and the different number of users served and in the care with which deliveries are made.

THE DELIVERY "HEAD."—How large the irrigating heads should be is a question of immediate and practical interest to every irrigation manager. No rule can be laid down and practice varies widely. With continuous flow as little as a single miner's inch, or about 0.02 second-foot, has sometimes been delivered as an irrigating head for furrow irrigation on 2-acre or 3-acre tracts, but such small heads are altogether unusual. In the citrus orchards of southern California where furrow irrigation is practised and where the irrigation water is distributed in underground pipes or flumes heads of 10 to 50 inches, or 0.20 to 1 second-foot are perhaps most common. In Modesto and Turlock irrigation districts, California, the practice is to give heads of from 15 to 20 and sometimes 30 second-feet for from 20 to 30 minutes per acre at each run, yet irrigators themselves often split the full heads into several smaller heads. These California figures represent the two extremes. As a rule such large heads as 20 to 30 second-feet are excessive and while theoretically economical in that they largely prevent uneven distribution in alfalfa checks, in the main they are believed to foster wasteful practice. The smaller heads are, of course, economical in special cases only. In most of the mountain states with continuous flow the irrigating head is based on the number of water shares owned by each irrigator and may be as little as 10 inches and in some cases as much as 100 inches or more. Under the largest system in Utah the stream delivered is usually from 2 to 4 second-feet. According to figures furnished by F. W. Hanna on the projects of the Reclamation Service practice varies widely with the different conditions met, as much as 12 to 20 second-feet being given as a maximum delivery head on some of the projects, with average deliveries on the same projects varying between 3 and 7.5 cubic feet per second. On Reclamation Service projects using the smaller class of heads, as on the Boise, Uncompahgre, Huntley, Sun River and Shoshone projects, the maximum heads vary from 2.5 to 4 second-feet and the average from 0.75 second-feet to 2 second-feet.

On the whole, the above data indicate that the head adopted on any system must be determined with reference to the particular conditions found. The soil and crop irrigated must govern, and distribution systems, including delivery gates,

must be designed to permit using the head that is the most economical. In general, the greater the slope and the more porous the soil, the smaller should be the delivery head adopted. Furrow irrigation accomplishes the best results by the use of relatively small streams after the furrows have once become wetted, and the head delivered can only be determined according to the number of furrows it is convenient to care for during irrigation at one time. In irrigating both grains and alfalfa in the mountain states the characteristic slope of the irrigated lands usually prevents applying in excess of 2 to 4 second-feet at one time, while the flatter slopes and more sandy soils of such places as the Great Valley of California and of the Southwest make heads as large as 10 to 15 second-feet economical of both time and water where check flooding is practised, much smaller heads being necessary for furrow irrigation.

A description of the more common devices used for the measurement of deliveries may be found under Art. 27.

32. Injurious Mineral Salts.—Portions of all soils are continuously being made soluble by numerous agencies. Abundant rains, which percolate through the soils of the earth's humid regions carry these soluble materials as they are formed, into the rivers, lakes, and oceans. Vast areas, however, have insufficient rainfall to leach away the soluble salts, thus giving rise to excess accumulation of these materials in arid soils. "Alkali," a term commonly given to all excess mineral salts, usually exists in the form of chloride, sulphates, and carbonates of sodium, calcium, and magnesium. Broadly speaking, the world over, alkali salts consist chiefly of sodium chloride, ($NaCl$), common salt; sodium sulphate (Na_2SO_4), Glauber salt; and sodium carbonate (Na_2CO_3) sal soda. The latter is commonly spoken of as "black alkali" since it dissolves organic matter and thus gives the soil surface a dark color, while the other salts which are less harmful to plants, form a white crust on the soil and are hence classed as "white alkali."

While it is very difficult to give maximum per cents. of plant tolerance to alkali, Hilgard's limits of 0.1 per cent. sodium carbonate, 0.25 per cent. sodium chloride and 0.50 per cent. sodium sulphate, observed for cereals in sandy loam soil are valuable as a general guide. In clay soils, the injurious pud-

dling or breaking down of crumb structure, especially by sodium carbonate, makes the limits very much less.

Much of the future success in the cultivation of alkali lands undoubtedly depends upon the use of plants resistant to soluble salts. The date palm, according to Swingle (Bul. 53, Bureau of Plant Industry, U. S. Dept. Agr.) is the most resistant of cultural plants. Kafir corn, sorghum, sugar beets, barley, rye, mature alfalfa, and asparagus are among the most resistant of ordinary crops, while wheat and oats tolerate very little alkali. Leguminous plants are as a class sensitive, although alfalfa and vetch are quite resistant. Hilgard reports that carrots, onions, and potatoes produce normal yields in soils strongly alkaline, but that the quality of the crops is badly affected. Grapes, olives, almonds, and figs are, in the order named, the most resistant fruit crops; while oranges, pears and apples are moderately tolerant; and, prunes, peaches, apricots and lemons rather sensitive.

Proper treatment of alkali soils will materially lessen the injurious effects of the excess soluble salts. Immediately after each irrigation large volumes of water are evaporated from the soil. A total loss of 3 acre-inches per acre in a period of 9 days, causing a deficiency in moisture to a depth of 10 feet has been observed by Widtsoe. As moisture moves upward in the soil, large quantities of soluble materials are carried with it to the surface where the salts are deposited, as the water passes off in vapor form. Suppose that a soil containing only 0.05 per cent. soluble salts, an ordinary amount in many productive lands, should have the entire amount, contained to a depth of 10 feet, deposited in the surface 6 inches. The surface content would be twenty times as great as before evaporation took place, thus making a total amount of 1 per cent. which is beyond plant tolerance. As a matter of fact, many soils in which "alkali" has been unsuspected, have been rendered worthless in just this manner. Clearly then irrigators must reduce evaporation from their soils.

Soils naturally alkaline, or those rendered such by faulty irrigation may be improved by (1) cropping with resistant plants, (2) removing surface incrustation, (3) turning under

surface soils, (4) chemical treatment, and (5) leaching by flooding and drainage.

About one-fifth of the dry weight of Australian salt brush and Russian thistle is ash or salt compounds, hence with 5 tons of dry matter harvested, 1 ton of salt would be removed. This may, in time, give some improvement. Moving the surface soil can be economically practised only on small areas or under other conditions, especially favorable. Turning it under will distribute the salts over a large area, and thus give at least temporary relief, while plants germinate and establish a root system to great depths. Chemical treatment, which is applied only to "black alkali" consists in adding calcium sulphate in amounts which depend on the amount of sodium carbonate in the soil, and vary from a few hundred pounds to several tons per acre. This method is valuable, even when leaching is contemplated, since it is very difficult to leach sodium carbonate. The less harmful sodium sulphate, formed by adding calcium sulphate, leaches with comparative ease. Its beneficial effects are reversed, however, if soils are irrigated to excess. Moreover, the noxious "black alkali" is actually formed in ordinary soils when they are swamped by heavy irrigation. Ultimately, however, leaching the excess salts by drainage is the only permanent method of reclamation.[1] This process was successfully tried in the vineyards of Fresno County, California, by V. M. Cone and the writer in 1907 and 1908. The upper 4 feet of soil before being treated contained on an average about 2/10 of 1 per cent. of soluble salts. After drain pipes had been laid in the vineyard, the surface formed into checks and each check flooded twice to a depth of 12 inches, the percentage of soluble salts was reduced to about 4/100 of 1 per cent.

33. The Use of Saline Waters in Irrigation.—Large amounts of soluble salts occur, not only in the soils, but also in the streams, lakes, and underground waters of the earth's arid region. The importance of plant tolerance to saline irrigation waters is therefore obvious. Some valuable observations have been made in connection with the use of such waters for irrigation, but no sys-

[1] See Drainage of Irrigated Lands in the San Joaquin Valley, Bul. 217, O. E. S., U. S. D. A.

tematic field experiments have been conducted for the purpose of determining plant tolerance to them. Reports of water analysis usually include all dissolved solids, but for agricultural purposes analyses of water for sodium carbonate (Na_2CO_3); sodium chloride ($NaCl$); and sodium sulphate ($NaSO$) will give a good index to its value. The amount of mineral salts contained in water is commonly reported in parts per 100,000.

The following classification of river waters, made by Stabler (Water Supply Paper No. 274 and Engineering News of July 14, 1910) furnishes irrigators a general guide in the use of saline waters.

TABLE NO. 28

Table Showing Classification of River Waters for Irrigation Purposes Based upon Amount and Composition of Dissolved Solids

Class Name of river	Place of sampling	Dissolved solids, parts per 100,000	Radicals in per cent. dissolved solids		
			Carb. (CO_3)	Bicarb. (HCO_3)	Chlor. (Cl)
Fair Rio Grande	El Paso, Texas	69.9	0.10	34.0	15.0
Fair Colorado	Yuma, Ariz	70.7	0.28	33.0	18.0
Fair Salt River	Roosevelt, Ariz	53.4	0.00	36.0	30.0
Fair Gila River	San Carlos, Ariz	73.6	0.04	35.0	30.0
Fair [1]Salt Fork of Red River	Near Mangum, Okla	230.0	0.00	6.2	9.5
Poor Turkey Creek	Near Olustee, Okla	317.0	0.00	6.1	12.0
Poor Pecos River	Near Carlsbad, N. M.	272.0	0.01	5.7	17.0
Poor North Fork of Red River	Near Headrick, Okla	359.0	0.04	5.3	33.0
Bad Elm Fork of Red River	Near Mangum, Okla	913.0	0.01	1.7	38.0

The calcium (Ca); sulphate (SO_4) sodium (Na) and other radicals are omitted from the table, hence the sum of the per cent. columns, as given above will never equal 100. Note that the Salt Fork of Red River, which contains a total of 230 parts dissolved matter per 100,000 is classed as fair. When it is observed that none of this material is carbonate, only 6.2 per cent. bicarbonate and 9.5 per cent. chlorine, the reason for the classification is obvious. The waters of these rivers, excluding the last two, have all been successfully used for irrigation. That special

[1] 52 per cent. of D. S. (SO_4) and 18 per cent. (Ca).

precautions are necessary to permanently maintain the productive capacity of soils in connection with the use of such waters is evident in view of experience in various localities as briefly mentioned in the following paragraph.

Certain orchard soils, irrigated, according to Forbes, with water taken from the Salt River, Arizona, which contained soluble salts varying in amount from 52 to 157 with a mean of 107 parts per 100,000, accumulated from 0.111 per cent. to 0.426 per cent. in a period of about 10 years (Arizona Bul. 44, p. 116). Two samples of Wyoming water which contained 5.71 and 23.58 parts alkali salts per 100,000, before irrigation, were shown by Slossen from analysis of the waste waters, to have made annual deposits in the upper 3 feet of soil which would in a period of 10 years, have amounted to 0.067 and 0.278 per cent. respectively (Wyo., Bul. 24, pp. 114 and 117). The Bureau of Soils, U. S. Dept. of Agri., speaking of conditions in the Pecos Valley, New Mexico, said, "Five hundred parts of soluble matter may be taken as the extreme limit of endurance for plants, while 250 to 300 mark the danger point at which the results of the use of water are very uncertain." That this estimate is conservative, seems evident in view of the fact that for centuries past waters containing from 400 to 800 parts per 100,000 have been successfully used in crop production, according to Means, by the Arabs in the Algerian Oases.

The remarkable success attained by the Arabs with such waters is dependent upon frequent, heavy application of water and thorough drainage by open ditches or tiles (Bureau of Soils, Cir. 10). The efficiency of frequent flooding is well illustrated in the following table after Forbes showing the relative alkali content in furrows and rows subsequent to the use of saline water in furrow irrigation.

Table No. 29

Depth in feet	Uncultivated tree row	Temporary ridges	Furrows flooded every 8 days
	Per cent. of alkali in soil	Per cent. of alkali in soil	Per cent. of alkali in soil
1	0.305	0.295	0.043
2	0.099	0.070	0.045
3	0.092	0.055	0.046

Note that the uncultivated row contains, in the first foot, 7 times as much salt as the furrow, and in the second and third, only twice as much as the soil under the furrow. Forbes noted further that the crest of a ridge in a strawberry plat contained 0.20 per cent. in the surface foot as compared to 0.061 per cent. in the bottom of the adjacent furrow. Hilgard observed that in a period of 3 years, water containing 170 parts of soluble salts per 100,000, caused complete defoliation of orange trees near Corona, California, and increased the per cent. of salts in the soil, originally, 0.0174 four times. He says further that the upper limit under ordinary practice in California is 120 parts. Water from artesian wells containing from 175 to 200 parts mineral salts per 100,000 have been successfully used for irrigation in South Dakota.

The general statement of permissible per cents. of mineral matter in irrigation water involves a knowledge of the character and relative proportion of the alkali salts; the crops grown; the soil texture, depth, and original alkali content; methods of irrigation; and drainage facilities. From the foregoing examples it is obvious that, although the parts of tolerable salts differ widely, under various conditions, evaporation must be reduced to a minimum and drainage provided when saline waters are used. Irrigation should be quickly followed by cultivation, especially where the furrow method is employed. Practical experience and chemical analysis agree in emphasizing liberal flooding and thorough drainage where saline waters must be used.

In case natural drainage is inadequate and artificial drainage impractical, the following method adopted by Israelson of calculating the number of acre-feet of water, containing a given amount of salt, which can be safely added to the soil may be valuable in helping irrigators to interpret an analysis of the water used. It assumes that all of the alkali salts contained in the irrigation water remain in the soil. An example will make it clear. Suppose the alkali content is 150 parts sodium chloride per 100,000 of water, the irrigation water penetrates to a depth of 6 feet, and that a cubic foot of soil weighs 1.32 times the weight of a cubic foot of water, a relation generally true. Let N equal the number of acre-feet per acre that can be safely added. By Art. 32 the maximum

amount of sodium chloride that ordinary plants can tolerate in the soil is 0.25 per cent., therefore the greatest number of pounds permissible in 6 acre-feet of soil is

$$\frac{0.25 \times 1.32 \times 62.5 \times 43{,}560 \times 6}{100}$$

The number of pounds chloride in 1 acre-foot of water would be $\frac{0.150 \times 62.5 \times 43{,}560}{100}$ as 150 parts per 100,000 $= 0.150$ per cent., 62.5 the weight of 1 cubic foot of water, and 43,560 the area of 1 acre in square feet. Hence,

$$N = \frac{0.25 \times 1.32 \times 62.5 \times 43{,}560 \times 6}{1.150 \times 52.5 \times 43{,}560} = 13.2.$$

If, therefore, 2 acre-feet of water are used annually, a period of 6 to 7 years would render the soil unproductive. From the above discussion, the general formula $N = \frac{1.32 \times Ps \times D}{Pw}$ is easily deduced where Ps equals the permissible per cent. of salt in the soil, Pw the per cent. of salt contained in the irrigation water, and D the mean depth in the soil to which water penetrates.

34. Drainage of Irrigated Farm Lands.—The drainage of land in an arid region differs in many essential features from the drainage of land in a humid region. In the former the soil in its natural state, except near the surface, has been continuously dry for ages. No percolating water has passed through it and in consequence no drainage arteries have been formed within its mass. It is not until water is conveyed and distributed in artificial channels over the land that these conditions are changed. These changes are often very radical in character. The river may no longer flow in its natural channel but be taken out and spread over large areas of dry soil. This soil and the numerous earthen channels which convey the water permit a large part to percolate and otherwise pass through the top layer of soil. Gravity and capillarity draw this escaping water lower and lower until some impervious stratum is reached along which it passes to lower levels. The intercepting of this waste or seepage water from the irrigated field and ditch forms an important feature in the drainage of arid lands.

Another feature of even greater importance is the presence of mineral salts known as alkali in amounts larger than the ordinary crops can tolerate. The greater part of these salts have to be removed and drainage systems are planned, not only to lower the ground-water level but to remove the harmful accumulation of alkali.

Charles F. Brown divides irrigated lands needing drainage into three classes (Farmers' Bul. 371). (1) Those injured by excess of water only, (2) those affected by an excess of botb water and alkali, (3) those having an excess of alkali only.

The Deer Lodge Valley in Montana is an example of the first class. The extensive drainage operations now in progress under the supervision of Dr. H. C. Gardner of the Montana Copper Mining Company reveal no harmful amounts of alkali. The soil is merely water-logged. The district southwest of Fresno City, California, is a good example of the second class. Here the ground-water level has risen in places to a height of over 60 feet as a result of the inflow of seepage water from irrigated lands and leaky ditches. The rise of the water table near the surface and the dissolving of mineral salts by it has accumulated so much alkali near the surface and to render much of the land unfit for the more profitable crops, such as raisin grapes and deciduous fruit trees (Drainage of Irrigated Lands in the San Joaquin Valley, O. E. S., Bul. 217). Much of the low-lying land bordering on Great Salt Lake is an example of the third class. Here virgin soil is so impregnated with common salt and other minerals as to be non-productive until the greater part of such salts have been removed by copious irrigations and underground drainage.

Need for Drainage.—Some engineers have gone so far as to advocate that all irrigated lands be provided with drainage systems. Since only a relatively small part of such lands require drainage it is manifestly unjust to impose so heavy a burden upon all farmers under irrigation enterprises. A better plan is to prevent, so far as practicable, the water-logging of raw lands and the rise of the alkali by a skillful use of water and by keeping the natural drainage channels open. In spite of all that can be done, however, in the way of preventative measures, a certain percentage of irrigated lands is certain to become in-

juriously affected by too much water, too much alkali, or both. Such tracts should receive early consideration in order that the proper remedy may be applied before valuable crops are destroyed and the soil rendered unproductive. The rise of the water table can be readily observed by the use of small test wells. The water in these wells can be analyzed to determine the kind and amount of mineral salts which it holds in solution. The height to which soil water may rise without injury to crops, varies with the seasons, crops and other conditions, but generally speaking, 4 feet below the surface is looked upon as the danger line.

In preparing the following paragraphs which aim to present an outline of the best drainage practice of the West, the writer desires to acknowledge his indebtedness to R. A. Hart supervising drainage engineer of the O. E. S., U. S. D. A.

Kind of Drains.—Covered drainage systems should be used for farm work as they are most efficient and more economical in the long run. Clay tile, cement tile or lumber-box conduits may be employed. Clay tile are to be preferred. They should be hard-burned but not brittle, of good shape and condition, free from blisters and serious cracks and have walls as impervious as possible and strong enough to bear the necessary weight of earth. Cement tile should only be used when clay tile is not available at reasonable rates. It should be machine-made, mixed wet, of proportions about 2:1 and should be steam-cured. Lumber-box conduits should invariably be supplied with bottoms and should be so constructed that their integrity of form will not depend on the nailing, since nails are soon destroyed by the salts. This may be accomplished by cutting shoulders in the tops and bottoms for holding the sides apart.

Depth of Drains.—Drains in an irrigated district should not be laid less than 6 feet in depth, save in exceptional cases where a thick impervious stratum is encountered at a less depth. Drains having a depth of 8 feet or more are much more effective, as a rule, but the additional cost of installing them is often prohibitive.

Location of Drains.—As a general thing drains should be located near the upper edge of water-logged areas or belts, but if the subsoil is coarse gravel it is preferable to locate the lines

in the lower parts and depressions. If considerable areas of comparatively level land, having fairly uniform soil conditions are to be drained, the lines may be located with some regularity from 200 to 500 feet apart, depending on the nature of the soil. Where conditions are irregular no rule for proximity of drains can be given except to state that the lines must be located so as to intercept the waste water along the line of its entrance to the field, which is usually at the foot of a change in slope from a steep to a lighter grade.

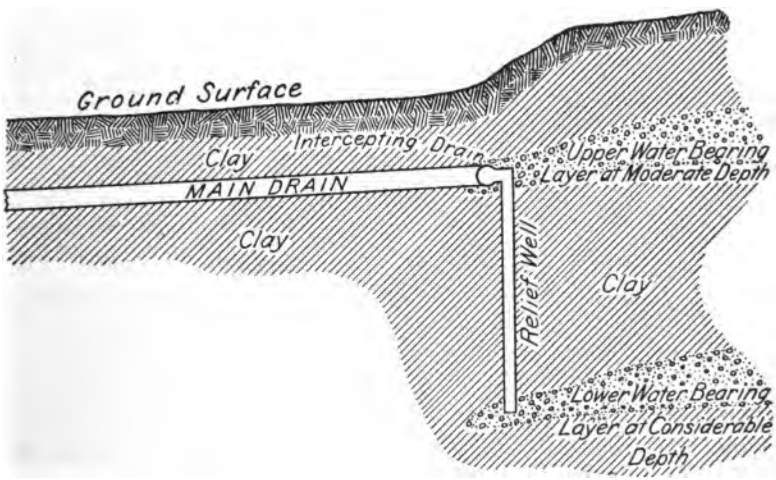

FIG. 60.—Plan and part elevation of drainage system, showing intercepting drains.

RELIEF WELLS.—In many cases, however, the seepage water comes from deep sources and is under pressure. Obviously there is a limit at which drains can be laid economically, but fortunately the seepage may be intercepted by means of relief wells so located as to connect the water-bearing stratum with a drain at ordinary depth. Fig. 60 shows the plan and part elevation of a drainage system so constructed as to intercept seepage from two distinct sources. The drain line cuts off the seepage from the upper stratum directly, while the relief wells convey the pressure water from the lower stratum to the drain. These wells may be bored with a post hole auger and should be cased or filled with coarse gravel.

Required Capacity.—It is difficult to give general rules regarding necessary capacity for drainage systems, but it is usually safe to provide a capacity of one-fifth the irrigation supply for lands having a clay subsoil and a capacity of one-half the irrigation supply for lands having a sandy subsoil. If the subsoil is coarse gravel it is necessary to determine the contributing area instead of the injured area and to provide a capacity of about one-half the irrigation supply of the area directly contributing.

Grade.—The carrying capacity of a tile of given diameter depends mainly on the fall of the drain. The smaller the drain the more grade is required. For the smaller sizes a fall of at least

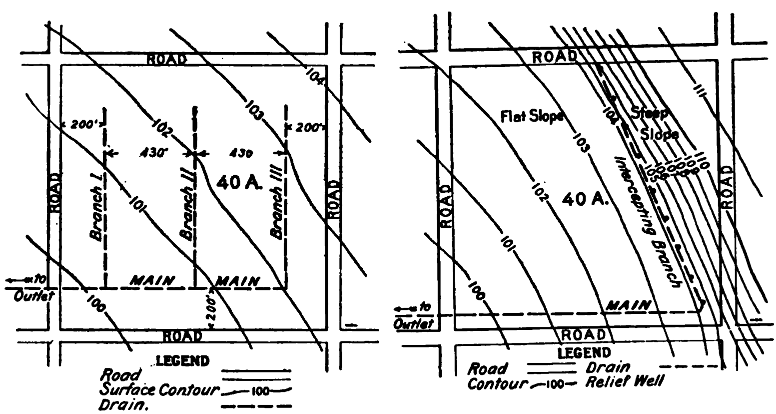

Fig. 61.—A common system of drainage as applied to an irrigated farm.

1 foot per thousand is required but where conditions permit 2 or more feet per thousand are preferable. For the larger sizes the fall should be at least a half-foot per thousand and where the necessary fall can be had double or even treble this grade may be advantageously adopted. Tile should be laid on a uniform grade so far as possible and in straight lines (Fig. 61).

Size of Tile.—It is not economical to use tile smaller than 6 inches in diameter and the use of tile less than 4 inches is not to be thought of. On the other hand it is rarely necessary to use tile larger than 12 inches in diameter for farm drainage. The latter size will take care of about a mile of drainage in gravel when laid on a grade of 1 foot per thousand. Nothing smaller

than an 8-inch tile should be laid in gravel and nothing smaller than a 6-inch tile in sand. A 12-inch tile will take care of the drainage developed by a system of 10 miles of laterals laid in a clay subsoil and of about 4 miles laid in a sand subsoil, on the above-named grade. As a general rule it may be stated that a given size of tile, up to 12 inches will carry as much water on the same grade as two lines of the next smaller size.

METHODS OF INSTALLATION.—The use of machinery for excavating is advisable whenever possible but ordinarily it will be found necessary to resort to hand labor. Owing to the fluxible nature of irrigated soils, it is generally found expedient to employ a small gang of men on each line and to complete the work in short sections, keeping the trenchers as close together as possible. Work must always commence at the outlet of each line and proceed up the slope so the developed water will readily drain away. The trench should not be opened ahead of the work, even to a shallow depth, and it is a fatal mistake to plow or scrape a trench in advance of the diggers. The trench should be cut from surface to grade as rapidly as possible and immediately thereafter the tile laid and blinded with a few inches of earth caved from the edges of the trench. By systematic, rapid trenching it is usually possible to proceed without much difficulty and at a reasonable cost but if, in spite of all precautions, caving in takes place, it will be necessary to brace the trench by means of long planks and short cross-pieces or sewer braces, and in special cases to sheet the trench tightly. These operations, of course, increase the cost greatly and should only be resorted to when all other measures fail. The best way to avoid difficulty is to choose the season of lowest ground-water table and to avoid storm periods. Irrigation water should be kept off the field that is being drained and also from higher and adjacent fields if possible.

The tile should be laid carefully, end to end, in a straight line and on an even grade. It is not necessary to separate the tile in any soil but in sandy or silty soils it may be necessary to protect the joints against the entrance of material. Burlap or cheesecloth doubled several times makes an effective filter. If gravel is available it is well to pack a quantity of graded material ranging from coarse sand to stones an inch in diameter about the joints, placing the coarser material next to the tile. The tile

should be blinded immediately, to prevent subsequent displacement in case of caving. If the material is very soft, it is advisable to lay boards under the tile to keep it in position and if it is impossible to keep sediment out of the line during construction it is well to operate sewer rods from openings in the line down the slope from the point where tile is being laid. It is also advisable to turn a stream of irrigation water into the upper end of each line for some time when the system is complete, in order to flush out sediment. Flushing should be resorted to if sediment makes its way into the drains at later periods. Almost any drain will be improved by occasional flushings.

BACKFILLING.—Actual backfilling should be done after the tile laying is complete and there is no better way of accomplishing this than by the use of a plow attached to a long pole evener, drawn by three or more horses. The spoil should be ridged up over the trench to allow for subsequent settling. Irrigation should not be applied directly over the completed trenches and canals and ditches should be carried across them in flumes.

MANHOLES.—Manholes in a drainage system serve several useful purposes. They offer an opportunity for observation of the flow of water and for access to the drain in case it becomes inoperative, so that cleaning devices may be easily inserted. Also by extending the manhole a foot or more below the tile level a basin is formed in which sediment may be trapped and removed from time to time. In soils that may be expected to enter the drains when wet, manholes should be installed at all junctions, changes in direction or slope and at intervals of not to exceed 500 feet on straight lines. In gravelly or compact soils they may well be eliminated. For observation purposes only nothing is better than a standpipe of 12-inch tile topped with a length of sewer pipe, provided with a cap. The bottom tile should have holes cut for the drain a foot above the bottom of the tile and gravel should be placed on the bottom.

COST.—On account of the varying soil conditions, effectiveness of drains and materials, and methods employed it is impossible to estimate with accuracy the cost of drainage of a given tract without making a special study of that tract. A summary of the experience that has been gained, however, warrants the fixing of certain limits of probable cost.

Outlet drainage systems cost from $3 to $15 per acre and often accomplish a great deal of farm drainage directly. At the latter figure, very little tile drainage should be necessary. Farm drainage, when single tracts or a collection of small units are handled, and the soil is stable, varies in cost from $10 per acre to $20 per acre with the average close to $14 per acre. If the soil is fluxible, however, or the material is so hard as to require picking, the costs run from $20 to $50 per acre and if the trenching work must be protected by sheeting the cost is often considerably more.

The cost of clay tile in the irrigated sections averages from about a cent per inch of inside diameter per foot of length in the smallest size up to 2 cents per inch of inside diameter per foot of length in the largest size ordinarily used. Trenching, laying tile and backfilling by hand in stable soil to an average depth of 6 feet, varies from 7 cents to 15 cents per foot. If the material is hard or unstable the cost will run up to 25 cents per foot and if sheeting is required the cost will be more than double this figure. Machine trenching is ordinarily much cheaper and 5-foot trenching has been contracted at about 4 cents per foot.

CHAPTER VI

IRRIGATION OF STAPLE CROPS

35. Alfalfa and Other Forage Crops.—Of the crops reported in the 17 Western States by the Census of 1910, 30.6 per cent. was in alfalfa, 21.1 per cent. in wild, salt, or prairie grasses, and 11.2 per cent. in other forage crops. These returns convey some idea of the importance of alfalfa and the preponderance of forage crops in western farming. The value of alfalfa to the West is more than double that of all other forage crcps combined and as indicated by the incomplete returns of the census probably exceeds $80,000,000 a year.

Notwithstanding its importance and value in irrigation farming, the profits on the area devoted to this crop can be greatly increased if more care and skill are exercised in growing it. The western irrigator has seldom been able financially to prepare his fields in such a way as to insure the most efficient irrigation and the highest profits. In consequence valuable water is wastefully applied to land that is in no fit condition to be irrigated. On the large acreage in irrigated alfalfa this amounts to an enormous loss. This is shown in the case of southern Idaho. There soil, water, climate and other conditions are unexcelled for the production of heavy yields of alfalfa and under good farming seasonal yields of 6 to 8 tons per acre can be harvested, yet the general average seasonal yield per acre in 1910 was only 3.26 tons.

Lands Adapted to Alfalfa.[1]—The most essential conditions for the production of alfalfa are abundant sunshine, a high summer temperature, plenty of moisture and a large, deep, well-drained soil. All of these essentials save moisture exist naturally in the arid region of the United States and when water is applied it makes conditions ideal. Over half a century of experience has

[1] See Farmers' Bul. 263 and 373, U. S. D. A., by the author.

shown that alfalfa can be successfully grown under a wide variety of soils and climate yet all western lands are not equally well adapted to its growth. For this reason those who are seeking such lands with a view to their purchase should first make a careful examination of the character and depth of soil, its behavior when irrigated, the slope and evenness of the surface, the presence of injurious salts and the facilities for drainage.

Preparatory Crops.—Experience has shown that it is difficult in the course of 6 months or a year to secure a good stand of alfalfa on raw land that has been covered by a desert growth. This is true particularly of rough, uneven land on which crop rotation is not practised. It is likewise true of land thickly covered with brush. It has been found impracticable in most localities to secure a smooth, well-graded surface where fresh roots interfere with the proper use of all grading and leveling implements. The same is true of hog-wallow land, where considerable soil has to be removed from the high places and deposited in the low places. It takes time and a second preparation of the surface before fields of this character can be put in good condition for the growth and irrigation of alfalfa. If crop rotation is to be followed the necessity for a preparatory crop is not so urgent, since the alfalfa will soon be plowed under to give place to another crop. In northern Colorado, where alfalfa usually follows either potatoes or sugar beets, the surface is not plowed, but merely harrowed or disked in the spring just before seeding. If the surface is uneven it is smoothed and leveled by means of a float or drag before the seed is put in. In southwestern Kansas it is likewise considered best to plant alfalfa after some cultivated crop which has held the weeds in check. The land is plowed in the fall to a depth of 6 inches, double-disked in the spring after the weeds have started, and is subsequently harrowed. In the vicinity of Los Banos, California, new land is almost invariably sown to barley or corn for two seasons before seeding to alfalfa. In Utah wheat or oats is preferred as a preparatory crop. The chief purpose of all such preparatory grain crops is to allow fresh roots of the original plant covering to decay, filled-in spots to settle, high places denuded of the upper layer of soil to weather, and in general to prepare a well-pulverized seed bed in a smooth, well-graded field.

Seeding Alfalfa.—In northern Colorado rotation of crops is practised and alfalfa seed is sown with a nurse crop, usually wheat or barley. The seed is drilled early in the spring with a common force-feed press drill equipped with an auxiliary seed box for alfalfa seed which is scattered broadcast between the rows and covered by the disk wheels of the press drill. From 12 to 20 pounds of alfalfa seed are sown to the acre.

In Yuma and other valleys of Arizona October planting is preferred. Frequently in this dry climate the land is irrigated before seeding. It is then cultivated, seeded and harrowed.

In the Sacramento Valley of California, alfalfa is seeded generally in the spring from February 15 to April 15. In the San Joaquin valley the time of seeding extends from March or earlier to April. The amount of seed used per acre in both valleys averages about 16 pounds.

The alfalfa growers of Montana are about equally divided in opinion as to the advantages of using a nurse crop. Those who seed grain with alfalfa claim that they get more out of the land the first season. Those who are opposed to this practice believe that the injury done to the alfalfa plants by the grain crop extends through several years and that the small gain of the first year is more than offset by the lessened yields of alfalfa in subsequent years. Mr. I. D. O'Donnell, one of the most successful alfalfa growers and feeders in the state is an advocate of the last-named practice.

The last half of August is the best time to seed alfalfa in the humid region. The soil is first plowed and heavily fertilized and early in the spring a hoed crop, preferably potatoes is planted. When this crop is harvested and the soil again properly prepared it is in excellent condition for alfalfa seed. The long growing season of the middle and south Atlantic states enables the plant to establish itself before the first killing frost. In seeding alfalfa in the humid region it is not safe to use less than 20 pounds to the acre.

Alfalfa as a Base of Rotation.—The benefits to be derived by rotating alfalfa with irrigated crops are now quite generally recognized and this practice is being followed by the more progressive communities of the irrigated region. Formerly when hay and grain crops comprised the bulk of the western soil

production, farmers were loathe to plow under a good stand of alfalfa because it was their best paying crop. In later years the raising of beets, potatoes, small fruits and truck have well nigh forced growers to rotate with legumes in order to maintain the fertility and good tilth of the soil.

On account of the slow growth of alfalfa during the first 4 to 6 months after seeding and the long period required to reach full maturity it is not adapted to short time rotations such as is practised so successfully in the more elevated and cooler portions of the irrigated West where red clover is sown with grain in the spring and in less than 18 months is plowed under. This simple rotation of grain sown with clover one season and clover alone the next year, giving large returns of both grain and hay could not well be followed with alfalfa for the reason named and for the additional reason that it requires at least 3 years for the roots of alfalfa to develop fully. So the most common alfalfa rotation in the West is 3 to 4 years in alfalfa, followed by root crops and a nurse crop of grain. If root crops are the most profitable the tendency is to grow them until the yields and profits fall off when the land is again restored by seeding to grain and alfalfa.

Influence of Irrigation in Root Development.—To develop a good tap root in the early stages of growth of alfalfa is desirable for many reasons. It enlarges the feeding ground of the plant and thus renders it more vigorous and a heavy yielder. It guards it from the bad effects of alternate dry and saturated surface soil by drawing moisture from beneath and it prolongs the life and usefulness of the plants by maintaining its most essential member in a healthy, normal condition.

When the top layer of soil is rich and kept continuously moist, alfalfa plants seem to put forth little effort to extend their tap roots far below the surface. The result is a division of the main root into several branches which spread out and become bushy.

To bring about deep rooting, the subsoil should be well drained. If water and worse still, water containing harmful quantities of salts, is allowed to rise into the feeding zone it will injure and in time destroy the tap root. The presence of hardpan or any formation which hinders root penetration likewise forces

shallow rooting. The remedy for this condition is deep plowing, subsoiling or else dynamiting. But even in well-drained, deep and thoroughly cultivated soils some incentive to deep rooting is necessary. This can readily be brought about by applying to the soil a scanty amount of water when the plant is young. At this stage it should suffer for water and this lack of moisture will tend to make it strike down through its tap root in quest of more. It is also a good plan to apply water some time before seeding if the soil is too dry.

Perhaps the greatest objections to sowing alfalfa with a nurse crop arises from the injury done to the root development of the alfalfa. In such a practice the fodder crop is overlooked in an effort to produce a good cereal crop. The latter requires water early on account of its quick-maturing properties and being shallow-rooted it requires a moist surface soil. Both are likely to affect injuriously the proper development of the roots of the alfalfa.

THE IRRIGATION OF ALFALFA. (a) *By Flooding.*—In the states of Colorado, Wyoming, Montana, and Utah and to some extent in all Western States, flooding, as it is termed, from field ditches and laterals is the most common method of irrigating hay and grain crops. As a rule a medium head of water is used. This is conducted through the supply ditch to the highest point of the field and is then divided into smaller heads and distributed among the farm ditches and laterals. From these in turn it is made to flow over the surface of the land, all excess water being collected by the lower laterals. The temporary field ditches are made to fit into the natural slope and configuration of the tract to be watered so as to conduct the water to the high places.

This method is well adapted to the varying slopes and irregular surface formation so common in the Mountain States. Fields which slope from 5 to 500 feet per mile can be successfully watered in this way. Besides the preparation of the land is easy and cheap since little change is made in the natural surface. On the other hand the labor required to irrigate is excessive and of the most fatiguing kind.

The manner in which forage crops are irrigated by flooding can best be shown by outlining the practice in a few localities.

In northern Colorado, for example, the head used varies from 2 to 4 second-feet and is divided into two or three laterals. Canvas or coarse manure dams are used to check the water in the laterals and to force it out over the banks and down the slopes of the fields. In less than 3 hours the upper foot of soil is usually thoroughly moistened. To apply one watering in this way costs from 15 to 30 cents per acre.

In Montana the field ditches are laid out across the slope on a grade of 1/2 to 3/4 inch to the rod or else down the steepest slope. In the first case the ditches are spaced 50 to 100 feet apart and water flows through openings in the bank made with the shovel and spreading out covers a wide space before reaching the next lower ditch. Each ditch carries from 40 to 80 miner's inches (1 to 2 second-feet) and one man can handle from 80 to 200 miner's inches in two or more ditches. The canvas dam is the most commonly used to check the flow in the ditch but earth and manure dams are also common. The earth is taken from the low side and when the dam is broken the hole is again partially filled with the same material. In making use of coarse manure for this purpose it is hauled by teams and distributed in small heaps along the ditch bank at intervals of 30 to 60 feet. Before irrigation begins it is placed in the ditch with a thin covering of earth over its upper face. The same manure can be used for several irrigations.

In other districts of Montana the field ditches are parallel and extend down the steepest slope from the supply ditch to the catch ditch at the bottom of the field. In this practice the check dams previously described are used. The laterals are made with a lister attached to a sulky frame, Fig. 62.

In Utah the head varies from less than 1 second-foot to as high as 5 second-feet. During the spring months when the streams are running bank full, large irrigating heads are the rule but as the stream flow diminishes the quantities used by the farmers likewise diminish. In this State, the farms, as well as the alfalfa fields, are smaller than those of neighboring states. One also finds more permanent ditches and turnout boxes.

(b) *By Borders.*—The borders or lands described under Art. 20 are used extensively for the irrigation of alfalfa. When

an alfalfa field is divided off into borders it can be watered at a low cost per acre and with little labor. It is therefore a paying investment to prepare the surface for this kind of application rather than for flooding whenever conditions are suitable. It calls for a fairly smooth, uniform slope of 5 to 20 feet per mile for any available supply of water of 2 to 10 second-feet. As a rule the borders or lands are too long. One is seldom justified in exceeding 900 feet between head ditches. On more uneven slopes a much shorter run is desirable. Several second-feet are turned into each border and the number of strips which can be watered simultaneously depends on the quantity of water available in the supply ditch. Immediately after a crop has been cut and removed a thin sheet of water will flow over the

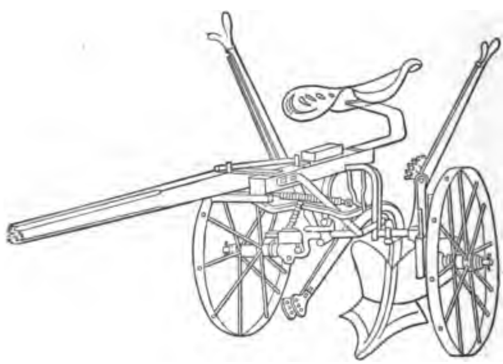

FIG. 62.—Lateral ditch plow.

stubble and down the border in a short time without backing up. Irrigation at this stage does not, therefore, require high border levees. On the contrary, due to the obstruction to the flow of water caused by the larger growth, the time required to irrigate a fairly well matured crop is much longer and the side levees require to be higher to prevent over-topping.

The most common size of borders in the Salt River valley of Arizona is 66 feet wide and 1320 feet long. A head of 300 miner's inches (7 1/2 second-feet) is turned into four borders. The time required to irrigate each set of four borders averages about 6 hours and the amount of water applied at a time varies from 2 to 4 acre-inches per acre. This water, however, is seldom evenly distributed throughout the length of the border. The

soil in the upper end may be moistened to a depth of 30 inches, that of the middle to a depth of 27 inches, while that near the lower end of the border may not be moistened to a greater depth than 15 inches.

(c) *By Checks.*—With a large volume in the feed ditch and a light sandy soil on a flat slope, alfalfa can be watered in checks at a low cost per acre for the season. In the Modesto and Turlock Irrigation districts of central California the feed ditches are designed to carry 10 to 20 second-feet. These large heads are used by the farmers in turn for short periods of time. Five second-feet flowing on a check containing 1 acre would cover it to a depth of 5 inches in 1 hour. If a head of 15 second-feet is available, three checks can be irrigated simultaneously. Irrigation begins with the higher checks and works down.

On the west side of the San Joaquin river under the Miller and Lux canal system, the check levees follow contour lines and enclose areas of 1 to 3 acres. The average head used is 8 1/2 second-feet and the time required to irrigate an acre varies from 1/2 to 1 hour and over. The checks and ditches under this system are not so well provided with boxes and gates as are those of the Modesto and Turlock districts and in consequence the cost per acre for the season is about 50 cents higher.

(d) *By Furrows.*—Alfalfa, clover and other forage crops grown in the State of Washington and in parts of Idaho and other states are irrigated by the furrow method. Where the soil is deep and fairly retentive of moisture, the furrows are spaced 3 1/2 to 4 feet apart but in sandy and shallow soil the spacing varies from 2 to 2 1/2 feet. The length of the furrow likewise varies with the character of the soil. In sandy soil 200 feet is considered sufficient whereas in the heavy and deeper soils it is customary to run water in furrows 330 to 660 feet or even longer distances.

In Washington the water is delivered, as a rule, in a continuous stream, 1 second-foot being allowed for 160 acres. By this custom the owner of a small farm of 20 acres receives only one-eighth of a second-foot, a flow altogether too small to apply economically. This defect in water contracts is partly overcome by an exchange of water among neighbors who in this way adopt a voluntary rotation system.

The head of water available is distributed to the furrows

from head ditches through lath or metal spouts. Wooden flumes and pipes of concrete, wood and galvanized iron sometimes take the place of head ditches in earth. A head of half a second-foot may be apportioned among 50 or more furrows and permitted to run from 6 to 12 hours in the lighter soils and from 1 to 3 days in the heavy soils. Alfalfa is irrigated after each cutting and occasionally between cuttings. The quantity of water applied at each irrigation is seldom less than 6 acre-inches per acre but there is always a certain percentage wasted by deep percolation.

(e) *By Surface Pipes.*—This method is described in Art. 19.

AMOUNT OF WATER REQUIRED.—Alfalfa requires more water than most crops. This is readily accounted for by the character of the plant, the rapidity with which it grows, the number of crops produced in one season, and the heavy tonnage obtained.

As a result of careless practice there is a lack of uniformity in the quantity of water used, the volume applied frequently being far in excess of the needs of the crop. The majority of the records collected and published by the Office of Experiment Stations show a yearly duty of water for alfalfa ranging from 2.5 to 4.5 feet in depth over the surface, while in quite a large number of cases the volumes applied would have covered the area irrigated to depths of 6 to 15 feet.

From the large number of measurements made on the duty of water it is possible to select some that possess great value, since they indicate what can be accomplished with a given quantity of water.

During the season of 1904 careful measurements were made by C. E. Tait of the amount of water used on the alfalfa fields in the vicinity of Pomona, Cal. The rainfall at Pomona for the winter of 1903–04 was much below the normal and amounted to about 9.1 inches. The quantity of irrigation water applied by pumping averaged 2.3 feet in depth and the yield of cured hay averaged from 1 to 1.5 tons per acre per crop, five or six crops being common. These figures are corroborated by many others collected in southern California. Perhaps in no other locality of the arid region is a greater tonnage of alfalfa obtained, yet in a climate of scanty rainfall having a long, dry, hot summer only a comparatively small amount of water is used. About a third

of the 9000 acres irrigated by the Riverside Water Company is in alfalfa and for the past 7 years the average depth applied has been 2.31 feet, while the depth of rainfall and irrigation water combined has averaged 3.18 feet.

In 1903 the writer, then Director of the Montana Experiment Station, applied different depths of water to seven plats of alfalfa with the results given in the following table. It will be seen that a high tonnage for so short a season as prevails in Montana was obtained from plat 5 with the use of 2 feet of water. By irrigating plat 6 seven times, and plat 7 eight times, it was possible to increase the yield to the amounts stated. The results of this experiment seem to confirm the best practice of southern California, which may be summed up by stating that in localities having an annual rainfall of about 12 inches remarkably heavy yields of alfalfa may be obtained from the use of 24 to 30 inches of irrigation water, providing it is properly applied.

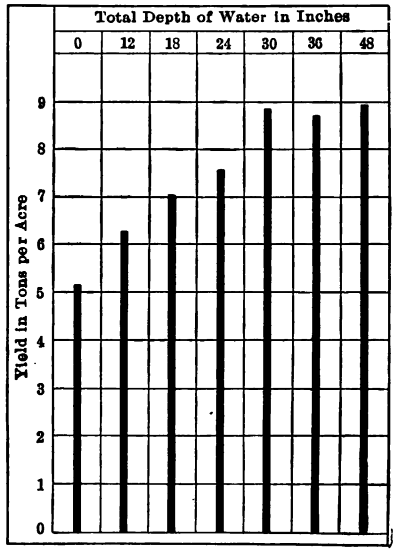

FIG. 63.—Average yield of alfalfa at Davis, Cal., from different quantities of water.

TABLE No. 30

Quantities of Water Applied to Alfalfa and Yields Secured, Montana Experiment Station

Plat number	Depth of irrigation, feet	Depth of rainfall, feet	Total depth, feet	Yield per acre of cured alfalfa, tons
1	0.5	0.70	1.20	4.61
2	None	0.70	0.70	1.95
3	1.0	0.70	1.70	4.42
4	1.5	0.70	2.20	3.75
5	2.0	0.70	2.70	6.35
6	2.5	0.70	3.20	7.20
7	3.0	0.70	3.70	7.68

Results similar to the preceding were obtained at Davis, California (Bul. 10, U. S. D. A.) during the years 1910 to 1912 inclusive. These results are summarized in Table 31 and Fig. 63.

TABLE No. 31

Summary of Results of Alfalfa Irrigation Investigations, 1910, 1911, and 1912

Depth of water applied	Yield in tons per acre			Value of hay per acre at $7 per ton			Cost of production			Net profit per acre		
	1910	1911	1912	1910	1911	1912	1910	1911	1912	1910	1911	1912
Inches												
0	3.85	6.02	6.52	$26.95	$42.14	$38.64	$8.65	$13.50	$12.40	$18.30	$28.64	$26.24
12	4.75	7.52	6.51	33.25	52.64	45.57	13.40	19.60	17.35	19.85	33.04	28.22
18	....	....	7.02	......	......	49.14	......	......	19.85	......	......	29.29
24	6.00	8.38	8.32	42.00	58.66	58.24	18.90	24.20	24.10	23.10	34.46	34.14
30	7.53	9.61	9.43	52.71	67.27	66.31	23.15	27.85	27.35	29.56	39.42	38.96
36	7.58	9.33	9.38	53.00	65.31	65.66	24.15	28.05	28.10	28.91	37.26	37.56
48	8.45	9.64	8.87	59.15	67.48	62.09	27.80	30.25	28.80	31.35	37.23	33.29
60	....	....	10.04	......	......	70.20	......	......	33.65	......	......	36.63

WINTERKILLING OF ALFALFA.—The winterkilling of alfalfa is confined chiefly to the colder and more elevated portions of the Rocky Mountain region and to the northern belt of humid states. Damage from cold is rare in Arizona and in California it is confined to young plants. In both the Sacramento and San Joaquin valleys of the latter State the seed is frequently sown in midwinter and the slight frosts which occur occasionally in December and January in both these valleys are severe enough to kill very young plants. The belief is common that the plants are safe after they have put forth their third leaf.

In the colder portions of Montana, Wyoming, Colorado, Utah, and the Dakotas alfalfa is apparently winterkilled from a variety of causes and sometimes from a combination of causes. The percentage of loss around Greeley, Colorado, has been placed at 2 per cent. per annum. In this locality and throughout the Cache la Poudre Valley in northern Colorado most of the winterkilling is done in open, dry winters and is quite generally attributed to a scarcity of moisture in the soil. In the winter of 1907 considerable damage was done to the alfalfa fields around Loveland, Colorado, on account of the long dry spell in midwinter. The old alfalfa fields suffered most. It was the opinion

of the farmers that a late fall irrigation would have prevented the loss.

Near Wheatland, Wyoming, the higher portions of the fields suffer most damage in winter, and here also the cause is said to be lack of moisture in the soil, combined with the effects produced by cold and wind.

At Choteau, in northern Montana, a farmer watered late in the fall, part of an alfalfa field which was 2 years old, and it winterkilled, while the unwatered portion escaped injury. This and other evidence along the same line which might be given go far to demonstrate that under some conditions too much moisture is as detrimental as too little.

Probably the chief cause of the winterkilling of alfalfa is alternate freezing and thawing. The damage from this cause is greatly increased when water is left standing on the surface. A blanket of snow is a protection, but when a thin sheet of ice forms over portions of a field the result is usually fatal to plants. The bad effects of alternate freezing and thawing on alfalfa may be observed at the edge of a snow bank. This crop is likewise injured by the rupture of the tap roots caused by the heaving of the soil.

From present knowledge of the subject, the means which may be used to protect alfalfa fields from winterkilling may be summed up as follows: Where both the soil and the air are dry the plant should be supplied with sufficient water for evaporation but the land should be drained so thoroughly that none of the top soil is saturated; a late growth should not be forced by heavy irrigations late in the growing season; if the soil is dry, irrigate after the plants have stopped growing; and the latest growth should be permitted to remain on the ground, unpastured, as a protection.

It may be stated in conclusion that the loss to the farmer from the winterkilling of alfalfa is not as great as might appear at first. The damage is done in winter and there is ample time to plow the plants under and secure another crop, which is usually heavy, owing to the amount of fertilizers added by the roots of alfalfa. The Montana farmer who increased his average yield of oats from 50 to 103 bushels per acre by plowing under winterkilled alfalfa illustrated this point.

36. Irrigation of Grain.—New irrigation enterprises have been settled for the most part by pioneering people who have but little capital. To settlers of this class the planting of small grain crops during the first years of their struggles with desert conditions is a necessity. Wheat and vegetables constitute the staple food supply for the poorer class, while corn, barley, oats and rye furnish food for both man and beast. Such crops as a rule require the smallest outlay to prepare the land for irrigation, and bring the quickest returns. They do fairly well on virgin soil and by their growth fit the raw land for such crops as alfalfa and clover. They also require water at a time when snow-fed streams are high and begin to ripen before the water supply runs low. For these and other reasons which might be named grain crops will continue to be of prime importance so long as farmers with limited means settle on the newly reclaimed lands of the West. On the other hand, the continuous cropping of grain, wheat in particular, should not be regarded as good management for the irrigated farm because of the small returns. As soon as the land is fit and the farmer is able financially to prepare the surface for more profitable crops, he should gradually convert the greater part of his grain fields into alfalfa, sugar beets, potatoes, truck, and fruit.

The results of growing grain under irrigation in rotation with other crops have been carefully studied by W. W. McLaughlin, in charge of irrigation investigations of the Office of Experiment Stations in Utah, and his able assistant, L. M. Winsor. The opinions of these men are regarded highly among grain growers in the Mountain States and in what follows the author has drawn freely from their published reports.

GRAIN IN ROTATION.—The chief advantages secured by rotating grains, legumes and root crops are larger and better yields, a more uniform draft on the plant food in the soil, the privilege of growing the crop best suited to markets, and greater immunity from plant diseases and crop failures. Grain used in rotation serves in many localities as a nurse crop for alfalfa and clover. However in planning a rotation it is obvious that the system adapted to one locality may not apply to another. Each system should be based on local conditions and take into consideration such factors as adaptability of soil and climate, concentrated prod-

ucts such as beef and cream, market conditions, size of farm, availability of labor, and the like.

Seasonal Rotation of Grain.—Largely as the result of experiments by the Irrigation Investigations force in California, grain raising in the Sacramento Valley, whether for hay or grain, has of late taken a new turn. Here the practice for a half century has been to sow in the fall or winter and rely upon the winter rains to provide moisture to mature the crop in the spring. The success which has attended the efforts of Messrs. Adams and Beckett in irrigating grain on the University Farm at Davis, California, has led to a change in plan. By making use of irrigation water any deficiency in the rainfall can be made up and when the grain is harvested in the spring the stubble can be irrigated, plowed and seeded to another crop. Professor Beckett is of the opinion that three crops can be grown on the same field each year provided the right use is made of both soil and water. In any event grain followed by a corn crop has been a demonstrated success provided the soil fertility is maintained by a proper rotation.

Preparation of the Soil.—Grain crops respond quickly at the start to a carefully prepared seed bed. On heavy soil it is not advisable to plow very deep at first, for the deeper soil, being less exposed to the action of the elements, is not so mellow or so well aerated; but each succeeding plowing should go a little deeper until the desired depth is reached, by which time the inactive subsoil shall have become productive. In breaking up new land it is advisable to remove if possible all the brush and roots because when turned under they keep the soil loose and open and cause the ready loss of moisture. Brush thus covered will remain sound for a long time before decaying and will be a constant source of annoyance while it lasts.

In order that the winter moisture may be stored for spring germination, it is advisable to prepare the soil early and the ground should be plowed in the fall. Fall-plowed ground should receive a little cultivation with a spring-tooth harrow as soon as it can be worked in the spring. In the absence of a spring-tooth, the best implement is the spike-tooth harrow with teeth at an angle of 45 to 60 degrees. The disk harrow should not be used in preparing full-plowed ground for seeding except perhaps in

rare cases, because it cuts too deep and the soil will dry out just as deep as it is disturbed. The object of this cultivation is three-fold; it pulverizes the surface mulch, it kills the first crop of weeds which start with the early warm days of spring, and it levels the rough surface of the land, leaving it in better condition for irrigation. If this method is followed, the moisture will be held near enough the surface so that the grain may be drilled from 1 to 2 inches into the moist earth which lies beneath the dry surface mulch.

Where it is necessary to plow in the spring care should be taken to have the ground sufficiently moist. It should not break up into dry clods or break down into a powdery ash heap. In the former case a suitable seed bed can not be secured and in the latter the soil will puddle after being wet. When plowed it should be dry enough to scour the plow and moist enough to turn over in a mellow state. When the soil is too dry it is better to irrigate before plowing even though plowing be delayed in consequence. The harrow should follow the plow. If a second team is not available then the land plowed in the forenoon should be harrowed before the team is unhitched at dinner time, that plowed in the afternoon should be harrowed before night. Where leveling is necessary it should be done immediately after plowing and should be followed in turn by light harrowing. This is essential in order to hold the moisture and to get the ground smoothed down to a seed bed while it is in a moist condition.

Seed and Seeding.—The time of seeding varies with the locality and variety of grain. Wheat may be sowed on unfrozen ground at any time from late August until well along in the spring months. Spring wheat should be planted early. It is generally conceded that the growing of fall or winter wheat is preferable to the growing of spring wheat except in sections where the former will winterkill. In growing winter wheat farm labor is more evenly distributed, less water and labor are required in irrigation and the crop matures earlier. These advantages also apply to the grains which can be grown in the fall.

In the case of spring barley and oats, early planting is not desirable. When sown too early these seeds sometimes rot before germinating and a good stand is not secured. The better plan is to have the ground well prepared with plenty of moisture

under a thin, fine mulch; then wait for warm spring weather and plant at a time when quick germination can be secured.

The depth of planting will depend somewhat on the condition of the soil. One of the advantages in using a drill in seeding is to secure a uniform germination which in turn insures a uniform ripening of the crop. When a drill is used in seeding the grain should be placed 1/2 to 2 inches in the moist earth which with a 2 to 2 1/2 inch mulch makes a total depth of planting of from 2 1/2 to 4 1/2 inches.

The variety of seed to use should be determined by local conditions, time of planting, market demands and various other factors. A safe rule to follow is to choose the variety which has been adopted by the majority in a community and found to give the best results. If any entire community is growing the same variety there will be little difficulty experienced in obtaining seed pure, which is one of the most important considerations in successful grain culture. Care should also be taken to secure grain seed which is true to type, heavy, and free from weed seed. This done, the next step is the proper treatment of the seed to prevent various diseases, principal among which is smut.

The Department of Agriculture and the state experiment stations have recommended various treatments to kill the smut spore without impairing the germinating power of the grain, such as a solution of blue stone followed by lime, immersion in hot water, sprinkling with or immersion in formalin solution, details of which are given in Farmers' Bull. 250 of the Department of Agriculture. The formalin treatment consisting of 1 pound of formalin of guaranteed strength and purity to 50 gallons of water is commonly used at the present time.

Irrigation before Seeding.—In many parts of the arid West the winter precipitation is so light that moisture sufficient for spring germination is not stored in the soil and it is necessary to irrigate to supply the deficiency. This may be done either before or after seeding. Although the latter practice is the more common, observations and the results of demonstrations in many western states point conclusively to the fact that irrigation before seeding rather than immediately afterward is generally the better practice. In the more retentive soils of the warmer states, water may be applied during the late fall or

winter months so as to store enough moisture in the soil to supply the needs of the plant until seeding time. In other localities the effect of fall plowing followed by soil moisture conservation may provide sufficient moisture without any artificial watering.

It is the land which is plowed in the spring that gives the most trouble. If it is too dry it should first be plowed and leveled, and then irrigated and harrowed when dry enough. The harrowing should be done with a spring-tooth or spike-tooth harrow. This treatment not only provides ample moisture near the surface but leaves the soil mellow and in good condition to insure an even and rapid growth of grain. It is only on the more retentive soils that this practice is likely to prove injurious in seeding.

Farmers who plow in the spring, put in the seed and take chances of the small amount of moisture in the soil being sufficient for germination, usually fail to harvest a full crop. The stirring of the soil causes a loss of moisture by evaporation in the top layer where the seed is placed, and as a result germination is incomplete and an immediate irrigation is necessary to obtain a stand. The application of water at this time is liable to form a crust through which the young plants can not force their way. This crust also tends to rob the soil of its moisture by producing a heavy evaporation and it is not long until a second or even a third watering is required. These frequent irrigations at the start produce shallow-rooted plants which are injuriously affected by the subsequent drying out of the top soil. The bad effects of "irrigating up" a crop, as it is called, may be partially remedied by harrowing the ground in the direction of the furrows when the plants are in the third or fourth leaf.

When to Irrigate.—There are two critical periods in the development of grain crops. The first extends from germination until the plants shade the ground, the second is at the flowering or fruiting stage. The plant must get a good start. Sufficient food is present in the parent kernel to start the root growth and to force the first leaf into view, after which it must shift for itself. If moisture is scarce at this stage the necessary food can not be obtained and a stunted growth results which can never be entirely overcome. Because of the necessity of giving the tender plant a good start it is important that the moisture should be supplied

beforehand so as to make it unnecessary to apply cold water, which always checks development at this stage of growth.

The second critical period and the one which is the most vital because of the sensitive condition of the plant, comes at the flowering or fruiting stage. More moisture is required at this time and immediately following than at any other stage of growth. To avoid a second shock care should be taken to supply plenty of moisture about booting time before the heads appear. This irrigation may suffice to bring the crop to maturity. However, if a shallow-rooted system has been developed by frequent previous irrigations or if even with a deep-rooted system there seems to be a scant supply of moisture, then it is advisable to give another light irrigation when the grain is in the dough. Otherwise it will not fill and will shrink in weight after harvest.

The character of the soil and subsoil (Farmers' Bul. 399) has a large influence on the time of irrigating. A heavy soil with tight subsoil will receive a large quantity of moisture and hold it for a long time, making it possible to irrigate heavily and at long intervals. A lighter soil which is underlaid with an open subsoil will not retain the water and it will become necessary to irrigate more frequently.

Many natural and artificial conditions influence the time and the amount of irrigation, and the farmer who best understands and makes use of them is the most successful. The condition of the soil, together with the appearance of the plant affords a practical test of the requirement of the plant for water. Grain which has plenty of moisture is of a light green color; but when the plant begins to suffer for water it turns to a dark green and the lower leaves begin to turn yellow. The presence of alkali in the soil may produce the same effect, however.

Quantity of Water to Apply.—The quantity of water to be applied at each irrigation depends upon the number of irrigations, depth of soil, nature of subsoil, the purpose for which the grain is grown, the condition of the crop, climatic conditions, and from a practical standpoint, the length of time between water turns, the available supply, method of application, the requirements of other crops, the expertness of the irrigator and the length of time the field has been under irrigation and cultivation (Farmers' Bul. 399).

As a general rule the soil is driest at the time of the first irrigation and more water will be required to irrigate properly at this time than subsequently. It is always safe to assume that the larger the growth of the straw the greater will be the quantity of water required at the time the head is making. Water for irrigation is generally plentiful during the early spring, but at the time the grain is filling the supply usually begins to fail. The usual practice of the farmers in the Mountain States is to irrigate heavily in the spring and use less water as the season advances.

The amount of water required by new land is usually more than that required by older land. The experience of the Bear Valley Canal Company in Utah affords an excellent illustration of the relative requirements in this regard. During the first years of irrigation in this valley a second-foot of water was used upon 60 to 80 acres and apparently the land required that amount. In recent years the amount of land actually served by a second-foot of water averaged 163 acres for grain crops. This decrease in the use of water is due in the first place to a rise of the ground water level and in the second to a better understanding of the water requirements of crops and improved methods of culture.

The time of irrigation in connection with the stage of growth has much to do in determining the amount of straw as compared with the amount of grain produced by the plant. The grain plant passes through a period when it is making straw and roots, and a period when it is making head. A heavy supply of moisture during the first period is conducive to a heavy growth of straw and leaves. If this is followed by a shortage of moisture during the second or heading stage, the heads will not fill and a shrunken kernel results. A proper supply of moisture at both stages insures a normal growth of straw with plump, well-filled heads of grain. These observations seem to indicate that the time of irrigation has more effect upon the results than does the quantity of water applied.

In general, beginning with grain under dry farm conditions, the yields can be slightly increased with each added amount of water until the maximum yield is reached. Beyond this point a condition is finally reached when an increased amount of water actually causes a falling off in yield. It may be well

to state in this connection that the increase in yield is not in proportion to the increase in water applied so that where water is scarce a heavy application may be given at a loss to the farmer even though the limit of application for maximum yield has not been reached.

The results of investigations made by Don H. Bark on the medium clay and sandy loam soils in southern Idaho in the years 1910, 1911 and 1912 show that the average amount of water used on 122 fields of grain was 1.45 acre-feet per acre. The rainfall during the three seasons of growth varied from 2 to 6 inches.

In the years 1899 and 1902 inclusive, the writer determined the amount of water used on 25 grain fields in three widely separated valleys of Montana and the average was found to be 1.31 acre-feet per acre. To this amount should be added the rainfall which averaged 0.42 acre-foot per season.

METHODS OF APPLYING WATER.—The experience of the Greeley colonists in Colorado and of others throughout the West goes far in demonstrating that grain growing year after year on irrigated land is not a profitable business. In order to yield fairly remunerative returns it must be rotated with other crops. Accordingly the preparation of land and the manner of applying water must also be adapted, not only to grain but to other crops in the rotation. At least three of the various methods previously described are suited to a combination of this kind. These methods are flooding, small furrows and borders.

Irrigating grain by flooding is the usual practice in Montana. There the field ditches, spaced from 60 to 90 feet apart, are made with a 14- or 16-inch double mouldboard plow attached to a sulky frame and drawn by three horses. The ditches are cleaned out with a steel or wooden shovel of the same width, drawn by one horse, Fig. 64. This implement also forms the earth dams in the ditches and is locally styled a dammer. The horse walks in the furrow made by the ditch plow and the loose earth in the bottom and sides is carried by the steel shovel and dumped in heaps about 60 feet apart. A stream of 100 miner's inches or thereabouts is turned into the supply ditch and divided between two adjacent field ditches. When one piece of ground is thoroughly soaked to a depth of 12 inches the dam is opened and the water rushes

through until it is checked by the next earth dam. By this method and with a good head of water one man can irrigate on an average 5 acres per day. If the flow of water is small and intermittent the average may be cut down to 2 acres. The second irrigation is applied in the same way but the amount of water used is considerably less.

In some sections of the West the field ditches, instead of being located on the grade lines extend down the steepest slope. Each irrigator is given about 125 miner's inches of water which is divided between two laterals. Instead of earth, half-rotted straw or stable manure is often used to form the checks, which

FIG. 64.—Dammer used in cleaning and damming field laterals.

are spaced about 65 feet apart. As soon as the first irrigation is completed the dams are re-set for the second irrigation. In re-setting the dams the manure or straw is mixed with the earth while both are kept damp thus forming a stronger and more impervious dam.

In irrigating grains by small furrows spaced 2 1/2 to 3 feet apart, commonly called corrugations (Art. 17), from 1 to 2 second-feet is turned into the head ditches and distributed among the furrows. One second-foot may well be divided among 50 to 150 furrows depending on the character of the soil and the slope of the field. The length of the furrows should not exceed that of a square 10-acre tract (660 feet) and when a 40-acre field is irrigated it should be divided into three equal parts

by head ditches, thus making the length of furrow in each part 440 feet. The water should be run long enough in the furrows to moisten the soil between them.

The irrigation of grain by the border method (Art. 20) does not differ in any essential from the description given elsewhere for the irrigation of alfalfa and other crops by this method.

Harvesting, Marketing and Profits.—Irrigated grain is confined to relatively small areas and has a long and heavy straw. Both of these conditions are unsuited to the combined harvester so commonly used on the dry farms and in the Mississippi valley. The sheaf binder is used almost universally in harvesting irrigated grain. This implement drops the grain bound in bundles either scattered or in piles. These are immediately placed in shocks by hand. Occasionally the bundles are hauled from the shocks to the farm stack yard to cure but more often they are hauled from the shocks directly to the thresher.

The well-managed irrigated farm has very little grain to market. But little wheat is grown and the oats, barley and corn or other grains are fed to stock of various kinds, thus insuring a much higher return than can be realized from the direct sale of the grain.

The returns which may be expected from grain where it is marketed direct are outlined by Professor McLaughlin in Farmers' Bul. 399.

37. Growing Root Crops under Irrigation.—Under this heading is included potatoes, sugar beets, sweet potatoes, turnips, etc., but in irrigated sections only the first two named are of sufficient importance to be considered here. Root crops are of greater relative importance in arid than in humid regions owing to the fact that under irrigation they produce heavy yields which are ordinarily sold for cash. Since the various operations connected with the cultivation, irrigation, harvesting, etc., of these two crops differ considerably they will be treated separately.

POTATOES

Climate.—Potatoes thrive in almost every section of the arid West. They are grown successfully in Wyoming at an elevation of 8000 feet and also at the lower elevations in the states along

the Pacific coast and are found from Montana on the north to New Mexico and Arizona on the south. Intense heat is detrimental to the potato. In general it may be said that for the best yield the mean temperature of the air should not rise above 70 to 75 degrees F. for any considerable time while the tubers are growing.

Soil.—Potatoes under irrigation require a loose friable soil with good under drainage, an ideal soil being a sandy loam with gravelly subsoil. A heavy clay or adobe soil is not well adapted to this crop.

Rotation.—Some system of rotation is very essential for the best results in the growing of potatoes, for continuous cropping will exhaust the soil in a short time and the yields will decline unless fertilizers are applied. Even though manure or artificial fertilizer is applied, fungus diseases, such as scab, will attack the tubers if they are grown on the same ground year after year. In the West, alfalfa or clover should be included in any rotation with potatoes in order to restore the nitrogen taken from the soil by the potatoes. Small grain and sugar beets can also be grown to advantage in such a rotation though many farmers simply grow alfalfa and potatoes alternately, letting the alfalfa remain 3 to 5 years or longer and following with potatoes for 1 or 2 years, never more than two. If grain is grown the order should be alfalfa, potatoes, grain; or alfalfa, grain, potatoes, grain. The advantage of the last named rotation is that the alfalfa is sometimes hard to kill out and if a crop of grain is grown preceding the potato crop the alfalfa will be effectually eliminated.

Preparation of Soil.—The ground should be carefully leveled to a uniform slope so that the irrigation water can be easily confined to the furrows. The importance of deep plowing, followed by a thorough harrowing in order to put the soil in good shape to receive the seed can not be too strongly recommended. If the season has been unusually dry it is sometimes advisable to irrigate before plowing in order to insure a liberal supply of moisture at the time of planting.

Seed and Planting.—Medium-sized potatoes, with clear, healthy skins and shallow eyes should be selected for planting. The grower will find it of advantage to select his seed potatoes

in the field, choosing seed from the large hills. Ground which has grown scabby potatoes the previous year should not again be planted to potatoes no matter how thoroughly the seed may be treated to prevent this disease. If there is danger of scab, ground should be selected where alfalfa or grain has been grown for a number of years. As an extra precaution it is well to treat the seed before cutting with a solution of corrosive sublimate or formalin or with gas. Farmers' Bul. 407 of the Department of Agriculture describes the preparation and use of these solutions. The pieces should not be cut too small, quarters or halves usually being recommended by the best growers. Many good authorities are now recommending the planting of whole potatoes of medium size.

The tubers should be planted 3 to 6 inches deep and 12 to 18 inches apart in rows 2 1/2 to 3 1/2 feet apart, depending on local conditions. Shallow planting is best on heavy soils, while on light sandy soils 6 inches or even more is not considered too deep. The amount of seed per acre depends, of course, on the distance between hills and the size of the seed pieces, but 700 pounds may be considered a fair average. Where this crop is grown on a commercial scale a planter should be used but great care should be exercised to get a uniform stand. Planting potatoes in plow furrows should never be practised as the seed should be entirely surrounded with soft earth to permit of the proper development of the roots and tubers.

Cultivation.—In arid regions frequent cultivation will aid greatly in conserving the soil moisture and may take the place of one or more irrigations. While the plants are quite small the field can be harrowed without injury and this kills the small weeds and serves as a cultivation. Other cultivations between the rows with an ordinary cultivator should follow rapidly until the vines are large enough to shade the ground when it is usually considered that no further cultivation is necessary although some irrigators prefer to cultivate after every irrigation so long as it can be done without injury to the vines. These later cultivations should be very shallow, however, in order not to injure the tubers.

Spraying.—It is sometimes necessary to spray potato vines to protect them against the ravages of the potato beetle. There

are machines on the market which enable the grower to get over his fields very rapidly and a thorough spraying at the right time greatly reduces the injury by the beetles. In Farmers' Bul. 407 the Bordeaux mixture is recommended. The method of making small quantities of this mixture is as follows: "Place 5 pounds of lime in one tub and slake this with sufficient water to thoroughly break up the lime without allowing it to burn. After the lime is slaked, dilute it to 25 gallons. Into another tub pour 25 gallons of water and suspend in it a 5-pound sack of copper sulphate for 24 to 48 hours. Bordeaux mixture is made by pouring these two solutions through a wire cloth sieve having about 18 to 20 meshes per inch, equal quantities of the two solutions being poured at the same time through the strainer."

IRRIGATION.—Potatoes should never be "irrigated up," that is, it should never be necessary to irrigate the field to sprout the seed, as it is impossible to get a uniform stand in that way. Care should be taken that sufficient moisture is in the ground at the time of planting to supply the needs of the plant for the first 20 days. Irrigation should be delayed as long as possible without checking the healthy, vigorous growth of the vines. Under ordinary circumstances the first irrigation is applied about the time the vines begin to bloom and from this time on until maturity the soil should be kept well supplied with moisture so as not to check the growth. Allowing the soil to dry out and then applying a copious irrigation is apt to produce knotty tubers and otherwise injure their quality.

Furrow irrigation is the only practical method for potatoes. The common practice in irrigating potatoes is to make an opening in the ditch bank with the shovel at intervals, one opening supplying water to several furrows. This method can be improved on by inserting wooden or metal spouts in the ditch bank for every other row and raising the water in the ditch by means of a check box or canvas dam until it flows through these openings. This enables the irrigator to control the flow of water in each furrow much better than by the first-mentioned plan. A rather unique method of supplying water to the furrows is employed in parts of Colorado and is shown in Fig. 65. When furrow *E* has been watered the ridge between it and furrow *F* is cut, the earth removed being placed in furrow *E* to turn the

water through the cut. This is repeated for the next furrow and so on until thè group of furrows supplied from an opening in the ditch has been watered.

Furrows should be made deep so as to allow the water to be drawn up to the vines by capillarity. This lessens the danger of saturating the soil and causing it to bake, a condition which should always be avoided if possible. At the last cultivation before the first irrigation the fenders should be taken off the cultivator and the shovels turned so as to crowd the

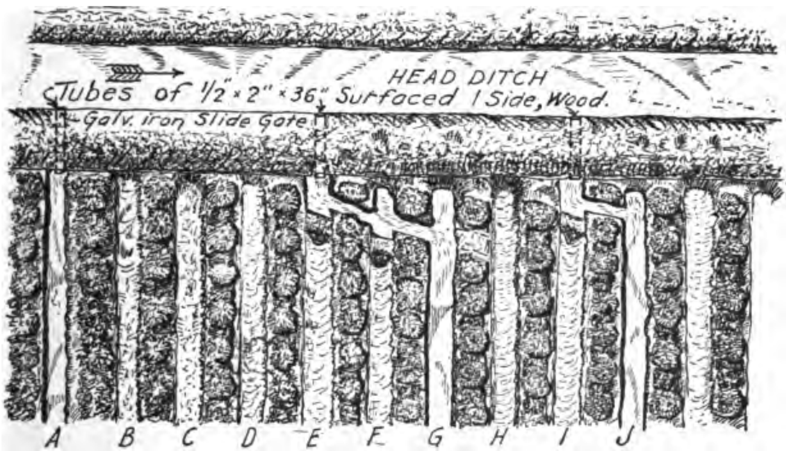

FIG. 65.—Method of distributing water from head ditch to potato rows.

earth toward the vines. The furrow thus made should be deepened by going over the field again, using double-winged shovels on the cultivator or a double mouldboard plow. This makes a furrow about 12 inches deep measured from the crown of the plants and 12 to 16 inches wide across the top. The chief advantages of deep furrows are: they provide an abundance of loose earth to place around the tubers; they lessen the risk of the water coming in contact with the vines; they prevent an excess of water around the tubers and they allow the moisture to be drawn up from below, thus supplying a constant and uniform quantity to the roots.

Where it is possible to get a large head of water, one irrigator can handle 2 second-feet without waste. With such a stream

he can keep water running in 40 to 50 rows at a time and under typical conditions, that is, with a slope of 25 feet per mile and rows 1000 to 1200 feet long, the water should reach the end of the rows in 3 or 4 hours. Where smaller heads must be used it is sometimes necessary to run water in the rows from 24 to 48 hours in order to thoroughly irrigate the crop. Two or three irrigations usually suffice to bring the crop to maturity. A well-known method of determining when the crop is in need of moisture is to dig into the earth near the tubers and press a handful together; if it crumbles apart when released the crop should be irrigated. When the vines have a dark green color it is also an indication that they need water.

Experiments conducted at the Experiment Stations of Idaho, Montana and Utah indicate that better quality and as good yields of potatoes can be secured by the use of a moderate amount of water. The amount required varies with the soil, and the season, but generally speaking the total amount applied during a season should not exceed 2 feet in depth over the field. With frequent cultivations and care in the distribution of the water a much smaller amount will be ample.

Opinions differ regarding the respective merits of applying water in every row or every alternate row. The majority of potato growers irrigate in every row but many employ the alternate method successfully. With a loose, friable, sandy loam which allows moisture to spread rapidly laterally water applied to every other furrow will moisten the intervening space sufficiently to maintain the proper condition of soil moisture. At the second irrigation the rows not watered the first time should be irrigated. Where only a small irrigation head is obtainable, and with a soil as described above, this method undoubtedly possesses merit.

Under any system of irrigation, care should be used to cease irrigating long enough before harvest to allow the ground to become dry so that the dirt will readily separate from the tubers when they are plowed out.

The writer is indebted to Mr. Guy Ervin, of the U. S. Department of Agriculture, for the following suggestions as to the best practice to follow in irrigating potatoes.

1. See that there is plenty of moisture in the soil at the time of

planting. Irrigate before planting if necessary but never irrigate to sprout the seed after planting.

2. Run a small stream of water in a deep furrow so that moisture will be drawn up to the tubers instead of soaking down to them.

3. Do not irrigate too soon. Wait until the crop is plainly in need of water and then keep the ground well supplied with moisture until the potatoes have matured.

4. Conserve the moisture and aerate the soil by frequent light cultivations. If this is done two or three irrigations will usually suffice.

Harvesting and Sorting.—When the skin of the potato is firm and can not be rubbed off and the vines are dead, the crop is ready to harvest. The work of digging, sorting and marketing or storing should then be rushed through in order to avoid danger of loss from freezing.

Where potatoes are grown on a commercial scale it is best to have a potato digger. Sometimes a number of farmers can combine and purchase a digger to advantage. There are a number of different makes on the market at varying prices. The machine should be kept some distance ahead of the pickers in order that the potatoes may have time to dry off before they are sacked.

The sorting can either be done in the field at the time of harvest or later when they are to be marketed but the former method is the better. There are also machines which sort the potatoes. These consist simply of a set of screens of different sized meshes which separate the small potatoes from those of marketable size.

Storing.—It is not always convenient or advisable to haul the potatoes directly to market from the field and it is therefore often necessary to provide storage for part of the crop at least. In building a storage house for potatoes it should be constructed so as to provide an even temperature just a little above freezing, a good circulation of dry air and convenient arrangements for putting in and taking out potatoes.

Fig. 66 shows an end elevation of a potato cellar near Idaho Falls, Idaho. The cellar is 98 feet long and 40 feet wide. The dimensions of the frame are as shown in the sketch. The sides and ends are boarded up with 1-inch rough lumber and the portions above the natural surface of the ground are banked with

earth and straw. The roof consists of 2-inch rough planking covered with a foot each of straw and packed earth. The main entrance is protected by a covered driveway 28 feet long, 11 feet wide and 9 feet high built of rough 1-inch lumber. There are six 1-foot square chutes in the roof on each side for use in filling the top part of the cellar and four 2 × 3-foot traps in center of roof to admit light and air. In cold weather the traps are covered with sacks and in very severe weather a covering of fresh barnyard manure is added.

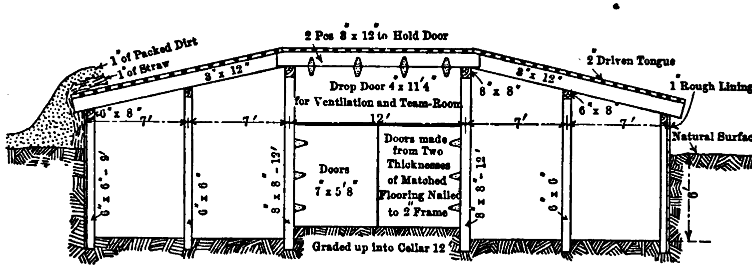

FIG. 66.—End elevation of a potato cellar.

MARKETING.—The man who grows potatoes commercially should keep in close touch not only with his local market but also with the large markets of the country. He should endeavor to ascertain just what characteristics a potato should possess to be a good seller and should strive to produce that kind of potato. Very large or very small potatoes are not in demand. A medium-sized potato, with shallow eyes and smooth, healthy skin will always command the highest price. If the grower contemplates holding his crop in storage for better prices he should take into account the extra labor involved, the loss from shrinkage of the stored crop and the danger of loss from freezing in very cold weather or from other causes. Cooperation among growers in raising uniform varieties and in marketing their crops is of great value in sections which are distant from large markets.

COST OF GROWING.—The cost of growing potatoes under irrigation varies somewhat due to the difference in the amount of seed planted, the price of the irrigation water, the yield, etc. However, it is believed the following tabulation represents the average cost of the various items. This does not include the cost of

fertilizer which if used would add $3 or $4, or taxes and interest on the value of the land.

Preparing ground	$2.50
Cutting seed and planting	2.00
Cost of seed	8.00
Cultivating and hoeing	4.00
Irrigating	4.50
Harvesting	8.00
Sorting	1.50
Sacks	5.00
Marketing	5.00
Spraying	2.00
Total	$42.50

The cost of the seed is the item subject to the greatest variation. This is readily understood when it is remembered that the amount of seed planted may vary all the way from 600 to 3000 pounds per acre.

Yields and Profits.—According to the Yearbooks of the Department of Agriculture, the average yield of potatoes in the United States for the 10-year period 1900–1909 inclusive, was 91 bushels per acre. In the 16 western states, however, the yield was about 150 bushels and if it were possible to determine the average yield on irrigated fields alone it would doubtless be found to be still higher. Yields of from 300 to 600 bushels per acre are not uncommon.

The price of potatoes fluctuates considerably from year to year and at different times of the year. The average farm price per bushel on December 1, 1910, was 55.7 cents, on the same date in 1911 it was 79.9 and again in 1912 it was 50.5 cents. Taking the country as a whole, this rise and fall in price is directly proportional to the production. The profit from this crop is therefore a matter of considerable uncertainty and especially is this true in small isolated valleys located at a distance from large markets. No attempt will be made here to state the net profits from the growing of potatoes more than to say that if the irrigation farmer will use care in the selection of seed and in the planting, cultivating and irrigating of his crop, he will find that it will add materially to his cash revenues 3 years out of every 4. His chief concern should be to increase the quantity and improve

the quality of his output and a careful application of the principles laid down in the foregoing, together with a study of the best practice in the community, will do much to accomplish this aim.

SUGAR BEETS

The growing of sugar beets is subject to conditions unlike those for any other crop. Owing to their bulk, sugar beets can not be shipped a long distance and it is therefore necessary that they be grown near a sugar factory. On the other hand the factory must be assured that a large enough acreage is planted to sugar beets each year to keep the plant running sufficiently long to make the enterprise profitable. The grower and the sugar company are therefore interdependent.

Sugar beet factories have capacities ranging from 400 to 1200 tons of beets daily and the "campaign" or time the factory runs is from 80 to 120 days, varying with the locality and the season.

Each sugar beet grower is required to enter into a contract with the factory before the beginning of the crop-growing season. These contracts provide that the grower shall prepare the area which is to be devoted to beets in a thorough manner and that the seed will be planted and the beets grown, blocked, thinned, harvested and delivered in accordance with instructions and under the supervision of duly authorized agents or field superintendents of the company. The company agrees to commence receiving beets as soon as they are matured. Instructions are given in the contracts regarding the harvesting, marketing and siloing of the crop. The company agrees to furnish the seed and do the planting at specified prices per pound and per acre, respectively. It is usually specified that the beets shall be of 80 per cent. purity and contain 12 per cent. of sugar or more. The price per ton for beets meeting the requirements in the contract is also stated and an additional 50 cents is paid for siloed beets. Not over 25 per cent. of the crop is allowed to be siloed and this only upon the request of the company. The growers are privileged to employ a man at their own expense satisfactory to the company, to check the tare and weights of the beets or the beet polarization of the laboratory. Settlement is made on or about the tenth of each month for all beets received during the first half of the pre-

ceding month and on the twentieth for the last half of the preceding month.

Sugar beets are grown successfully on almost all classes of soil from heavy black adobe to sandy and silt loams. The heavy soils are of course harder to cultivate but if properly handled such soils will produce a large tonnage of beets high in sugar content.

According to investigations conducted by the Bureau of Chemistry a number of years ago, a climate with a mean summer temperature of 70 degrees F. is best for sugar beets. They grow luxuriantly in warm climates but the sugar content is very low while in colder climates the growing season is too short. It is also essential that there be an absence of rain at the time of harvest, since a season of wet weather near the time of harvest, will cause a renewal of growth which reduces the sugar content of the beet. This is one thing which makes the West the ideal section for sugar beet culture since the water can be applied or withheld at will.

Rotation of crops is just as essential in the growing of sugar beets as with other crops. One instance is recorded where a field was cropped to sugar beets for 7 successive years with the result that the tonnage was reduced from 33 to 14 tons per acre. The most common rotation is to follow beets with grain, then alfalfa, then potatoes or other cultivated crop and back to beets again. Beets should not be grown more than 3 years in succession and 2 is preferable.

Preparation of Soil and Seeding.—In preparing a field for seeding, deep fall plowing (10 to 12 inches) is generally considered very essential. Except in California it is thought best to allow the field to remain in its rough condition so as to catch the snow and to allow the soil to be thoroughly aerated. In early spring it is double-disked, irrigated if necessary and replowed to a depth of 3 or 4 inches. After this second plowing the ground should be harrowed down to a fine seed bed. This last is very important since the beet is a tender plant at first and needs every possible encouragement to develop its root system.

The seeding is usually done by the sugar company, the company furnishing the seed and doing the seeding at prices stated in the contract. An ordinary four-row force-feed beet drill is used, 15 to 25 pounds of seed being sown per acre. The seed is planted 1

to 2 inches deep, and the rows are spaced 16 to 20 inches apart or they may be alternately 16 and 24 inches apart. The time of seeding in California extends from the end of October to May. In most other sections of the West the time is from April 10 to May 20. Sometimes rain falls before the beets have sprouted and a crust forms. This crust must be broken and the usual methods are to harrow the ground with the teeth of the harrow slanting back or to use a corrugated roller. In Farmers' Bul. 392 it is stated: "Seemingly the best way is to use 'spiders' on a beet cultivator. . . . The sharp points of the implement prick into and break up the crust without otherwise disturbing the top soil."

Care of the Young Plants.—In caring for the young plants there are a number of operations necessary in addition to frequent cultivations with horse cultivators. The first of these is called blocking and thinning. The blocking is done with a hoe by cutting out part of the young plants, leaving the remainder in bunches 8 inches to 1 foot apart from center to center. All but one plant in each bunch are then removed by hand. This gives the beet sufficient room to grow to a desirable size. Beets weighing 1 to 3 pounds are preferable. This work is usually done by contract and often small plants which should have been pulled are overlooked and these are removed at the second hoeing which follows in about 10 days. A third hoeing is usually necessary following the first irrigation which consists chiefly of cutting out or pulling the large weeds which are missed by the cultivator. A cultivation should follow each hoeing and each irrigation but this is not done in some localities. In Colorado very few growers cultivate after irrigation begins. However, since the cost per acre for each cultivation is not more than 35 or 40 cents, the benefits of cultivating after each irrigation are more than worth the additional expense.

Irrigation.—As with other row crops, it is very important that a field intended for beets be carefully leveled to a uniform slope before the crop is planted. The benefits from such a course will be felt as long as the land is farmed. If there are irregularities in the field, part of the crop will suffer from lack of water and other parts will get too much and it will be impossible to confine the water to the furrows.

The furrow method is used almost exclusively in all western states except California and Kansas. In these latter states

flooding in checks or borders is practised. This is due to the fact that winter irrigation is practised to a great extent, most of the water being applied before the crop is planted. Slip joint pipe is also used in parts of southern California, and in the neighborhood of Lewiston, Utah, and southern Idaho a method of subirrigation is practised. These methods are the same for sugar beets as for other crops and have been described elsewhere in this volume.

Where furrow irrigation is employed the furrows are made with a furrowing sled or with a cultivator, using the furrowing shovels and fenders. The furrowing sled is a homemade device and is described in Farmers' Bulletin 392 as follows: "It is made of 6 by 6 inch timbers 42 inches long as runners and spaced wide enough to straddle two rows. These timbers are set to run on edge and are sharpened at the forward point and armed with old furrowing shovels which about fit them. The runners are securely spiked together at the back end with 2-inch boards upon which the driver rides and are connected in front by a 4 by 4 inch timber to which the draft is attached." While this implement makes a smooth furrow and is inexpensive it is not used very extensively because of the time required to make the furrows in this manner.

The furrows receiving water from one supply ditch should not exceed 500 feet in length and 300 feet would be better in most cases. Cross ditches should therefore be constructed at intervals of 300 to 500 feet at right angles with the beet rows for all ordinary slopes. These consist simply of furrows made with a single or double mouldboard plow. Water is supplied to the furrows in much the same way as described for the irrigation of potatoes.

Irrigation should be deferred as long as possible in order to encourage the roots to strike deep into the soil. If water is applied too soon it is apt to result in an over-development of the tops at the expense of the roots. Water should only be supplied as needed throughout the growing season. From 2 to 4 applications are usually sufficient. Beet tops may wilt during hot days even when the ground is abundantly supplied with moisture but if they still appear wilted in the early morning it is a sign that they are in need of water. The ground should never be allowed to become dry enough to check the vigorous growth of the beets. Irrigation should be discontinued long enough before harvest to allow beets

to mature. This is usually 4 to 6 weeks but the grower must use his best judgment in this matter combined with an observance of the practice of the most successful growers in the community.

Some difference of opinion exists as to the relative merits of night and day irrigation. Those who advocate day irrigation claim that they can control the water better in the day time and thus insure a more even distribution and less waste. The advantages of night irrigation are that water will go farther at night due to less evaporation, that the temperature of the water is higher and that there is less danger from scalding. In many sections where a system of rotation is practised irrigators are compelled to irrigate both night and day since they are only allowed to use the water for a stated period. Where night irrigation is practised either from choice or necessity it is of great advantage to have the field thoroughly leveled and lath boxes, tubes or other devices in the ditches to feed the water to the furrows in small uniform streams.

HARVESTING.—The harvesting like the planting and cultivation of sugar beets, is done under the supervision of the sugar companies. About the time the beets are maturing the field agents of the factory take a number of beets from various parts of the field and have them tested for purity and sugar contents. If they are found to meet the requirements, orders are issued to the grower to harvest the crop.

If the ground is soft enough to permit, a beet puller is used to plow out the beets. This consists of two prongs which run one on either side of the row close to the beets. This raises and loosens the beets so that they can be easily freed from the soil. If the ground is hard a beet plow is used, an implement somewhat like a subsoil plow. After these implements come a crew of men who gather the beets into windrows or piles, cut off the tops at the point of the lowest leaf and pile them up preparatory to hauling to the dumps or factory. If the piles have to be left in the field over night the beet tops are thrown over them to protect them against possible damage from frost. As rapidly as possible the beets are hauled to the factory or loading station. Sometimes it is impossible to get cars fast enough to take care of the beets as they come in and provision is usually made in the contracts for piling beets at the loading station until cars can be obtained.

SILOING.—In the Rocky Mountain States it is not possible usually for the factory to take care of the entire crop at the time of harvest and it becomes necessary to store or silo a part of the crop until such time as the factory can receive them. This consists simply of piling the beets carefully, the piles averaging from 1000 to 2000 pounds each, and covering them with a 6 to 12-inch layer of dirt, leaving a small space at the top for ventilation. As previously stated, 50 cents additional is paid for siloed beets to compensate for the additional labor.

COST OF GROWING.—Farmers' Bul. 392 itemizes the cost of growing sugar beets as follows:

Plowing land 10 to 12 inches deep	$3.00
Harrowing, leveling, cultivating, and preparing seed bed	2.00
Drilling in seed	0.50
20 pounds seed	2.00
Cultivating five times at 40 cents	2.00
Furrowing twice	1.00
Irrigating three times—labor	3.00
Thinning, hoeing and topping—contract	20.00
Plowing out	2.00
Hauling at 50 cents per ton (17 ton crop)	8.50
Water charge for maintenance of canals	0.75
Total	$44.75

YIELDS AND PROFITS.—The average yield of sugar beets throughout the arid region is only about 10 to 12 tons per acre. With such a yield the profit is very small but with proper care the yield should be much larger. Yields of 15 to 20 tons are usually obtained by successful growers and as high as 36 tons have been recorded. The price per ton does not fluctuate as much for this crop as it does for most field crops so if the grower gets a good yield he is practically assured of a good profit.

38. Irrigation of Orchards.—Four years ago the writer prepared an article on this subject which was published as Farmers' Bul. 404 of the U. S. Department of Agriculture. The more important features of this publication are reproduced in this article, together with such modifications and additional information as the experiences of the past 4 years seems to warrant.

SELECTION OF LAND.—Care and good judgment should be exercised in the selection of an orchard tract. If it turns out well

the profits are high, but if it fails the losses are heavy. It involves the setting aside of good land, the use of irrigation water and somewhat heavy expenses in purchasing trees, setting them out and caring for them until they begin to bear.

Assuming that the climate and soil of the district selected are adapted to the kind of trees to be grown, the next most important things to consider are good drainage and freedom from early and late frosts. Low-lying lands under a new irrigation system should be regarded with suspicion, even if the subsoil be quite dry at the time of planting. The results of a few years of heavy and careless irrigation on the higher lands adjacent may render the lowlands unfit for orchards. On the other hand, the higher lands are not always well drained naturally. A bank of clay extending across a slope may intercept percolating water and raise it near the surface. Favored locations for orchards in the mountain states are often found in the narrow river valleys at the mouths of canyons. The coarse soil of these deltas, the steep slopes, and the daily occurrence of winds which blow first out of the canyons and then back into them, afford excellent conditions for the production of highly flavored fruits at the minimum risk of being injured by frost.

Proper exposure is another important factor. In the warmer regions of the West and Southwest a northern exposure is sometimes best, but as a rule the orchards of the West require warmth and sunshine, and a southerly exposure is usually more desirable. Natural barriers frequently intercept the sweep of cold, destructive winds, and when these are lacking, wind-breaks may be planted to serve the same purpose. Depressions or sheltered coves should be avoided if the cold air has a tendency to collect in them, a free circulation of air being necessary to drive away frost. The low-lying lands seem to be the most subject to cold, stagnant air.

While experience has shown that orchard trees of nearly all kinds can be successfully grown on soils that differ widely in their mechanical and chemical composition, it has also shown that certain types of soils are best adapted to particular kinds of trees. Thus the best peach, almond, apricot, and olive orchards of the West are found on the lighter or sandier loams; the best apple, cherry, and pear orchards on heavier loams; while walnut, prune,

and orange orchards do best on medium grades of soil. The requirements of all, however, are a deep rich, and well-drained soil.

Grading the Surface.—As a rule fruit trees are planted on lands previously cultivated and cropped. One of the best preparatory crops for orchards is alfalfa. This vigorous plant breaks up the soil and subsoil by its roots, collects and stores valuable plant foods, and when it is turned under at the end of the second or third year leaves the soil in much better condition for the retention of moisture and the growth of young trees.

An effort should be made to establish a fairly uniform grade from top to bottom of each tract. This is done by cutting off the high points and depositing the earth thus obtained in the depressions. The length of the furrows should not exceed one-eighth of a mile and in sandy soil they should be shorter. As a rule, it is not difficult to grade the surface of an orchard so that small streams of water will readily flow in furrows from top to bottom.

Time to Irrigate.—The best orchardists believe that frequent examinations of the stem, branches, foliage and fruit are not enough. The roots and soil should likewise be examined. The advice of such men to the inexperienced is: Find out where the bulk of the feeding roots is located, ascertain the nature of the soil around them, and make frequent tests as to the moisture which it contains. In a citrus orchard of sandy loam samples are taken at depths of about 3 feet, and the moisture content determined by exposing the samples to a bright sun for the greater part of a day. It is considered that 6 per cent. by weight of free water is sufficient to keep the trees in a vigorous condition.

Dr. Loughridge of the University of California, in his experiments at Riverside, Cal., in June, 1905, found an average of 3.5 per cent. in the upper 2 feet and an average of 6.16 per cent. below this level in an orchard which had not been irrigated since October of the preceding year. It had received, however, a winter rainfall of about 16 inches. On examination it was found that the bulk of the roots lay between the first and fourth foot. These trees in June seemed to be merely holding their own. When irrigated July 7 they began to make new growth. A few days after the water was applied the percentage of free water in the upper 4 feet of soil rose to 9.64 per cent. The results of these

tests seem to indicate that the percentage by weight of free moisture should range between 5 and 10 per cent. in orchard loams.

Many fruit growers do not turn on the irrigation stream until the trees begin to show visible signs of suffering, as a slight change in color or a slight curling of the leaves. In thus waiting for these signals of distress, both trees and fruit are liable to be injured. On the other hand, the man who ignores these symptoms and pours on a large quantity of water whenever he can spare it, or when his turn comes, is apt to cause greater damage by an overdose of water.

Applying Water.—Orchards are irrigated for the most part from furrows. The manner in which water is distributed from head ditches or pipes to furrows and the location, spacing and depth of furrows were described under Furrow Irrigation. Practice differs as to the amount of water which is turned into each furrow and the number of hours it is permitted to flow.

In Southern California a miner's inch of water (1/50 second-foot) is usually allowed to run in each furrow until the soil is moistened to a sufficient depth. The heads used vary from 30 to 60 miner's inches.

In the Payette Valley, Idaho, 200 or more miner's inches are turned into the head ditch and divided up by means of wooden spouts into a like number of furrows. On steep ground much smaller streams are used. The length of the furrow varies from 300 feet on steep slopes to 600 feet and more on flat slopes. The time required to moisten the soil depends on the length of the furrow and the nature of the soil. In this locality it varies from 3 to 36 hours.

J. H. Foreman owns 20 acres of bearing orchard under the Sunnyside Canal in the Yakima Valley, Washington, and waters it four times in each season with 14 miner's inches (0.35 cubic foot per second). He makes three furrows between the rows, which are 40 rods long. The total supply is applied to one-half the orchard (10 acres) and kept on 48 hours.

On the clayey loams of the apple orchards on the east bench of the Bitter Root River, Montana, Prof. R. W. Fisher has found, as a result of experimenting, that it requires from 12 to 18 hours to moisten the soil in furrow irrigation 4 feet deep and 3 feet sideways.

In 1908 Mr. Struck, of Hood River, Oregon, irrigated 3 acres of apple trees in furrows 360 feet long, spaced 3 feet apart. About a miner's inch of water was turned into each alternate furrow from a wooden head flume and kept on for about 48 hours. After the soil had become sufficiently dry it was cultivated, and in 8 or 10 days thereafter water was turned into the alternate rows, which were left dry during the first irrigation.

In irrigating the deciduous orchards in the Sierra foothills of Placer County, Cal., very small heads are required in order to prevent erosion on the steep slopes. The continuous flow of 3 to 4 miner's inches is sufficient for a 20-acre orchard during the irrigation season which extends from May 1 to October 1. As a rule, there is but one furrow for each row of trees. This may extend down the steepest slope encircling the upper half of each tree in its course or it may extend in a diagonal direction. A tiny stream no larger, on steep slopes, than a pencil is permitted to run for 24 to 48 hours and is then changed to another furrow.

Number of Irrigations.—For nearly half the entire year the fruit trees of Wyoming and Montana have little active, visible growth, whereas in the citrus districts of California and Arizona the growth is continuous. A tree when dormant gives off moisture, but the amount evaporated from both soil and tree in winter is relatively small, owing to the low temperature, the lack of foliage, and feeble growth. A heavy rain which saturates the soil below the usual covering of soil mulch may take the place of one artificial watering, but the light shower frequently does more harm than good. The number of irrigations likewise depends on the capacity of the soil to hold water. If it readily parts with its moisture, light but frequent applications will produce the best results, but if it holds water well a heavy application at longer intervals is best, especially when loss by evaporation from the soil is prevented by the use of a deep soil mulch.

In the Yakima and Wenatchee fruit-growing districts of Washington the first irrigation is usually given in April or early in May. Then follow three to four waterings at intervals of 20 to 30 days. At Montrose, Colorado, water is used three to five times in a season. At Payette, Idaho, the same number of irrigations is applied, beginning about June 1 in ordinary seasons and repeating the operation at the end of 30-day intervals. As a rule, the

orchards at Lewiston, Idaho, are watered three times, beginning about June 15. From two to four waterings suffice for fruit trees in the vicinity of Boulder, Colo. The last irrigation is given on or before September 5, so that the new wood may have a chance to mature before heavy freezes occur. In the Bitter Root Valley, Montana, young trees are irrigated earlier and oftener than mature trees. Trees in bearing are, as a rule, irrigated about July 15, August 10, and August 20 of each year. In San Diego County, Cal., citrus trees are watered six to eight times, and deciduous trees three to four times in a season. In Placer County, Cal., deciduous trees are watered every 2 weeks.

Duty of Water.—The duty of water for 1 acre as fixed by water contracts varies all the way from one-fortieth to one four-hundredth of a cubic foot per second. In general, the most water is applied in districts that require the least. Wherever water is cheap and abundant the tendency seems to be to use large quantities, regardless of the requirements of the fruit trees. In Wyoming the duty of water is seldom less than at the rate of a cubic foot per second for 70 acres. In parts of southern California the same quantity of water not infrequently serves 400 acres, yet the amount required by the fruit trees of the latter locality is far in excess of that of the former.

In recent years the tendency all over the West is toward a more economical use of water, and even in localities where water for irrigation is still reasonably low in price it is rare that more than 2 1/2 acre-feet per acre are applied in a season. This is the duty provided for in the contracts of the Bitter Root Valley Irrigation Company, of Montana, which has 40,000 acres of fruit lands under ditch. Since, however, the water user is not entitled to receive more than one-half of an acre-foot per acre in any one calendar month, it is only when the growing season is long and dry that he requires the full amount.

In the vicinity of Boulder, Colo., the continuous flow of a cubic foot per second for 105 days serves about 112 acres of all kinds of crops. This amount of water, if none were lost, would cover each acre to a depth of 1.9 feet. In other words, the duty of water is a trifle less than 2 acre-feet per acre.

In 1908, the depth of water used on a 21 1/2-acre apple orchard at Wenatchee, Wash., was measured and found to be 23 inches.

The trees were 7 years old and produced heavily. This orchard was watered five times, the first on May 13 and the last on September 23. In San Diego County, Cal., 1 miner's inch (1/50 second-foot) irrigates from 6 to 7 acres near the coast where the air is cool and evaporation low, but 20 miles or so inland the same amount of water is needed for about 4 acres.

On the sandy loam orchards of Orange County, Cal., it has been demonstrated that 2 acre-inches every 60 days are sufficient to keep bearing trees in good condition. The rainfall in this locality

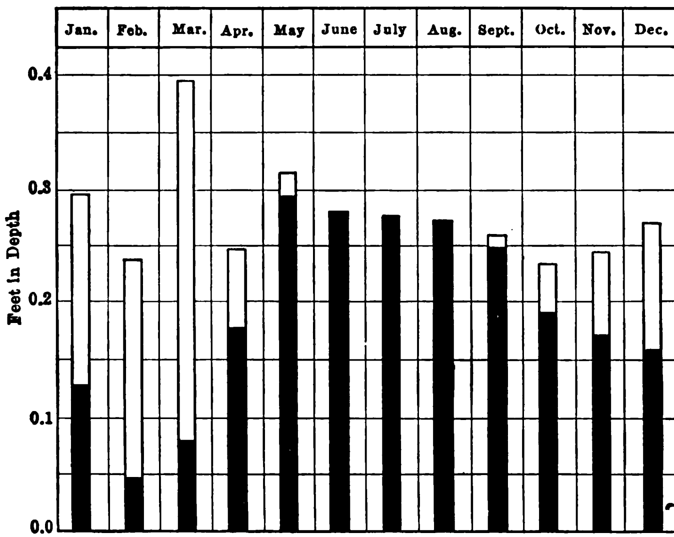

FIG. 67.—Average duty of water per month under Riverside Water Company, Dec. 1, 1901, to Nov. 30, 1908.

averages somewhat less than 12 inches per annum, but about 95 per cent. of the total falls between November and May, inclusive.

The most reliable and in many ways the most valuable records pertaining to duty of water on orchards have been obtained by the water companies of Riverside County, Cal. Here more or less irrigation water is used every month of the year. Fig. 67 is a graphic representation of the average amount of water used per month in a period of 7 years by the Riverside Water Company in irrigating about 9000 acres, of which nearly 6000 acres are planted to oranges and the balance to alfalfa. The figures given

in the diagram represent depth in feet over the surface watered. In the following table is given the average duty of water per month in acre-feet per acre under the same system from December 1, 1901, to November 30, 1908, a period of 7 years. The table also includes the average monthly rainfall at Riverside, Cal., for the same period and adding the quantity of water applied in irrigation in any one month to the rainfall of that month gives the total moisture received by the soil.

TABLE No. 32

Water used under Riverside Water Company's System, 1901–1908

Month	Average depth per acre, feet	Average rainfall, feet	Total water applied, feet	Month	Average depth per acre, feet	Average rainfall, feet	Total water applied, feet
December	0.159	0.109	0.268	July	0.272	0.002	0.274
January	0.123	0.170	0.293	August	0.269	....	0.269
February	0.046	0.190	0.236	September	0.243	0.015	0.258
March	0.078	0.316	0.394	October	0.189	0.043	0.232
April	0.177	0.068	0.245	November	0.169	0.073	0.242
May	0.291	0.023	0.314	Total	2.29	1.01	3.30
June	0.274	0.003	0.277				

INTERCROPPING.—The large majority of California fruit growers do not grow marketable crops between the trees. They believe in clean culture, except where leguminous crops are used to renovate and fertilize the soil. From the standpoint of the large commercial orchard and the well-to-do proprietor, this practice has much to recommend it. The planting of such an orchard is regarded as a long-time investment. Little, if any, returns are expected for the first few years, but when the trees approach maturity, and are in full bearing the anticipated profits are supposed to compensate the owner for all the lean years. Any treatment, therefore, which tends to rob the soil of its plant food when the trees are young or to retard their growth is pretty certain to lessen the yields and the consequent profits in later years. Prof. E. J. Wickson, director of the California Experiment Station, tersely expressed the prevailing opinion on this question in California in his work, "California Fruits and How to Grow Them" in the following language: "All intercultures are a loan made by the trees to the orchardist. The term may be long and

the rate of interest low, but sooner or later the trees will need restitution to the soil of the plant food removed by intercropping."

Mr. S. W. McCulloch, who controls 150 acres of citrus orchards in southern California, goes further in stating, "It is always detrimental to the development of an orchard to grow crops between the trees. In some cases the effect is not marked aside from securing less rapid growth, but it will affect the crops of fruit for several years and in the end nothing will be gained."

Notwithstanding all this, the poor man must needs make the loan or his children may starve. The settler on a small tract set out to young trees cannot afford, if his means are limited, to wait 4 or 5 years for the first returns. He must produce crops between the rows, and the question for him to consider is how this can be done with the least possible injury to the trees. A plentiful supply of water and a deep rich soil are the essentials of intercropping. In districts that depend on a meager rainfall of 15 to 20 inches per annum, or where irrigation water is both scarce and costly, the practice becomes of doubtful value under any circumstances. In most of the fruit districts of the West water for irrigation is still reasonably low in price, and the extra amount required for intercropping represents but a small part of the net gains from such crops.

Shallow-rooted plants are considered the most desirable for this purpose. Squash, melons, sweet potatoes, tomatoes, and peanuts are the most common in California. The cultivation is done with one horse and a small cultivator. A clear space 3 to 4 feet wide is left on each side of the young trees. In the Verde River Valley of Arizona, strawberries, lettuce, onions, and melons are raised in the young orchards. In parts of Idaho, alfalfa fields are frequently plowed under to plant trees. When this is done, berries, beans, melons, onions, and tomatoes can be grown between the rows for several years without any apparent injury to young trees. In northern Colorado, raspberries, gooseberries, currants, as well as corn, beans, and peas are often planted in orchards, while in southwestern Kansas the order is usually cabbage, melons and sweet potatoes.

In the young apple orchards of Hood River Valley, Oregon, strawberries are frequently planted between the rows. The manner in which this is done, as well as the system of contour

planting which is there practised, is shown in Fig. 68. The manager of a large apple orchard company in Montana states that no appreciable effect is noticed on apple trees as a result of growing potatoes, cabbage, beans, onions, and other vegetables between the trees providing the intercrops are well cultivated and irrigated. In the fruit districts of Washington, intercropping is a common practice. In 1907 a fruit grower raised in 10 acres of two-year-old trees cantaloupes, tomatoes, peppers, cucumbers, corn, radishes, beans, peas, potatoes, and turnips, all of which netted him $2,086.50, or an average of $208.65 an acre.

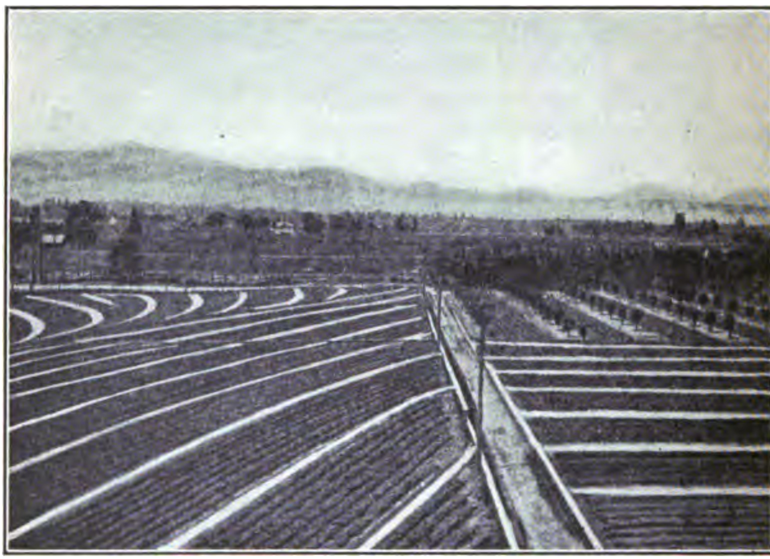

FIG. 68.—Orchard showing strawberries between rows of trees.

While opinions differ regarding the wisdom of growing such crops as have been named between the tree rows, most fruit growers are convinced of the beneficial effects of cover crops. Notwithstanding the scarcity and high value of water in the Riverside citrus district, the superintendent of a large fruit company has for years grown peas and vetch in the orange and lemon orchards under his management, and advocates the free use of irrigation water to supplement the winter rains for the rapid and vigorous growth of such crops. In the walnut groves of Orange

County, Cal., bur clover is sown in the fall, given one or two irrigations during the winter if the rainfall is below the normal and plowed under in April.

The cost of such cover crops as peas, vetch, or clover includes the seed, the labor of sowing it, the water, and the time required to apply it. These items, according to Dr. S. S. Twombly, of Fullerton, Cal., amount to from $2.50 to $3.25 per acre. Twenty tons per acre of green material is perhaps an average crop. In this tonnage there would be about 160 pounds of nitrogen, which at 20 cents per pound represents a value of $32 per acre for a cover crop like vetch.

Other beneficial effects of cover crops are quite fully summarized by Prof. W. S. Thornber, horticulturist of the Washington Agricultural Experiment Station (Wash. Sta. Pop. Bul. 8).

WINTER IRRIGATION.—When water is used outside of the regular irrigation period, or what is in many cases equivalent, outside of the growing season, it is termed winter irrigation. Over a large part of the arid region the growing season is limited by low temperatures to 150 days, or less, and when the flow of streams is utilized only during this period much valuable water runs to waste.

It was for the purpose of utilizing some of this waste that the orchardists of the Pacific Coast States and Arizona began the practice of winter irrigation. The precipitation usually occurs in winter in the form of rain, and large quantities of creek water are then available. This water is spread over the orchards in January, February, and March, when deciduous trees are dormant. The most favorable conditions for this practice are a mild winter climate; a deep, retentive soil which will hold the greater part of the water applied; deep-rooted trees; and a soil moist from frequent rains.

The creek water which was applied to some of the prune orchards of the Santa Clara Valley, California, during the winter of 1904 was measured by the agents of irrigation investigations with the following results: From February 27 to April 23, 1241 acres were irrigated under the Statler ditch to an average depth of 1.58 feet. From February 12 to April 23, 2021 acres were irrigated under the Sorosis and Calkins ditches to an average depth of 1.75 feet. In the majority of cases the orchards which

are irrigated in winter in this valley receive no additional supply of moisture other than about 16 inches of rain water.

In the colder parts of the arid region winter irrigation is likewise being practised with satisfactory results. The purpose is not only to store water in the soil but to prevent the winter-killing of trees. Experience has shown that it is not best to apply much water to orchards during the latter part of the growing season, since it tends to produce immature growth which is easily damaged by frost. In many of the orchards of Montana no water is applied in summer irrigation after August 20. Owing, however, to the prevalence of warm chinook winds, which not only melt the snow in a night, but rob the exposed soil of much of its moisture, one or two irrigations are frequently necessary in midwinter.

39. Irrigation of Rice.—The total acreage devoted to rice growing in the United States in 1912, was, according to the December Crop Report of the Department of Agriculture for that year 722,800 acres; the production was 25,054,000 bushels valued at $23,423,000. The distribution of the area in rice in that year was as follows:

State	Acres	Per cent. of total
Louisiana	352,600	48.78
Texas	265,500	36.73
Arkansas	90,800	12.56
So. Atlantic States	12,500	1.73
California	1,400	0.19
Total	722,800	99.99

In 1896, the forerunner of the modern pumping plant for the irrigation of rice was operated for the first time near Crowley, Louisiana, marking the beginning of a new era in the development of irrigated rice in this country. Largely as a result of better facilities for securing and controlling an adequate water supply, the yield of cleaned rice increased from 116,000,000 pounds in 1897 to 520,000,000 pounds in 1907.

During the past 5 years questions of water supply, canals, application and duty of water, and the effect of water on rice production have been carefully investigated by C. G. Haskell of Irrigation Investigations, Office of Experiment Stations, U. S.

Department of Agriculture. The writer has drawn freely from Mr. Haskell's publications and acquired knowledge on this subject in preparing the following article.

Soil, Climate and Water Supply.—Practically all of the rice grown in the United States is irrigated, and irrigated rice to be profitable requires the right kind of soil and subsoil, a suitable climate, and an adequate water supply. Any rich loam or clay soil that is level enough to be economically irrigated, if underlaid with a compact clay subsoil, impervious to water, is suitable for rice culture. If the land is rolling or broken, water can not be easily kept on it, and if the subsoil is loose, there will be such a loss of water that irrigation will be very expensive. Not more than two successive rice crops can be grown profitably on very sandy loam soil. The crop must likewise have at least 4 months of warm weather and no cool nights during heading time.

The water used in rice irrigation is derived from streams, lakes, bayous, and wells. More than 97 per cent. of the water used is pumped and over one-quarter of this is pumped from wells. A very small acreage is irrigated with stored water from wells, and a similar area with water stored in shallow reservoirs and allowed to flow to rice planted on lower land. Sometimes rice planted on low land receives its irrigation from the inflow of water from surrounding higher fields. This is the so-called "Providence" method. Along the Atlantic coast several thousand acres of rice are grown on low land near the mouths of rivers and are irrigated by fresh river water backed up over it during high tides.

Preparation of Land, Planting and Seeding.—On the prairies the land is generally plowed with sulky or gang plows. Along the Mississippi River and the Atlantic coast where negro laborers do most of the work the walking plow is generally used. The land is disked and harrowed to make a good seed bed and the rice is planted with a drill or sometimes with a broadcast seeder. Along the Atlantic coast the rows are made 15 inches apart to allow the rice to be cultivated, but in all other sections rice is not cultivated and the rows are made about 7 inches apart.

In Louisiana, Texas and Arkansas, Honduras and Shinriki (Japan) rices are the principal varieties grown for commercial purposes, although during the last few years several varieties have been developed in this country which do better than the

imported rices. The Honduras is a tall rice with coarse stalks and wide leaves. The heads and the grains in the heads hang long and are light colored. The Japan rice is short with small wire-like stalks and narrow leaves. The head and grains are shorter than the Honduras rice. By reason of the large number of heads per plant, Japan rice makes larger yields than the Honduras, but it does not bring as high a price on the market. On the Atlantic coast the famous Carolina Gold Seed and white rice are grown. The Gold Seed is about the size of the Honduras rice and is known by the golden color of the hulls. About 90 pounds of Honduras or 65 pounds of Japan rice are generally planted to the acre.

Canals, Pumping Plants, and Laterals.—The irrigation canals which carry the water from the streams and lakes to the lands to be irrigated are built on high ground and sometimes extend 30 miles from their source. The larger canals are merely two parallel levees built upon the surface of the ground from 200 to 275 feet apart, and since their grades are very flat they are really long reservoirs in which water flows very slowly. The slow velocity causes little loss of head and keeps the total lift at the pumping plant at a minimum. This is essential, for the cost of the water depends largely upon the height to which it is elevated. From the main canals the water is conveyed to the fields in laterals.

Some of the largest and best equipped pumping plants in the world pump into irrigation canals from the streams of southwestern Louisiana and southeastern Texas. They are frequently equipped with large horizontal centrifugal or rotary pumps, operated by compound condensing Corliss engines. Steam is generally supplied from horizontal water-tube boilers and petroleum is often used for fuel.

Wells.—A large part of the land upon which rice is grown is underlain with waterbearing beds of sand and gravel at depths varying from 40 to 1000 feet. Great improvements have been made during recent years in methods of drilling and equipping wells. Practically all of the water obtained from wells is pumped. The average of the discharges from over 800 wells in Texas, Arkansas, and Louisiana is 950 gallons per minute. Some wells supply as high as 3000 gallons per minute and irrigate about

400 acres of rice. Irrigation water from wells enables much land to be planted to rice which is out of reach of the river, bayou or lake canals and could not otherwise be irrigated. The greater part of the irrigation development in the rice country during recent years has been along the line of irrigation from wells.

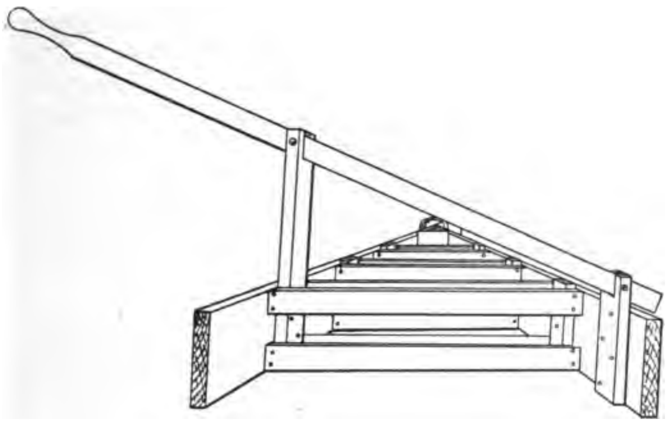

FIG. 69.—Push for building levees and digging small drainage ditches.

FIELD LEVEES.—High levees are built around the field to prevent the escape of water. Other levees are built across the field on contours to hold the water on the land. A contour field levee is built on the surface of the ground for every drop of three-tenths of a foot. Sometimes the levees are located on every two or

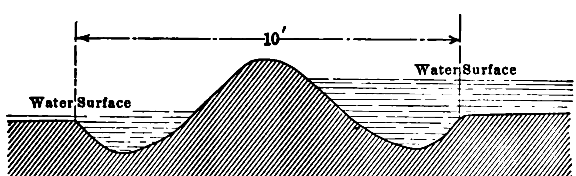

FIG. 70.—Cross-section of the common high field levee.

four-tenths of a foot drop. The field is thus divided into irregular shaped cuts depending in size upon the slope of the ground. All the land in each cut is of nearly the same elevation. Fig. 69 shows a wooden "push" that is generally used to build levees and to dig small drainage ditches.

In the newer or more up to date rice farms the cross levees are built wide so that teams can work them and rice can be grown upon them. Fig. 70 shows a cross section of a common, narrow, high, field levee. Fig. 71 shows a cross section of a low, wide, field levee.

STRUCTURES TO CONTROL THE FLOW OF WATER ON FIELDS.—Drainage ditches are provided so that water can be removed from any cut, when desired. If the soil is loose, sandy loam, wooden gates are placed in the field levees to regulate the flow of the water and to prevent the levees washing out. Sometimes a sack is placed so the water can flow over it to answer the purpose of a gate. The lateral or small canal which carries the water supply should be built along the side of the field so that water can be applied to any cut without flooding those above it.

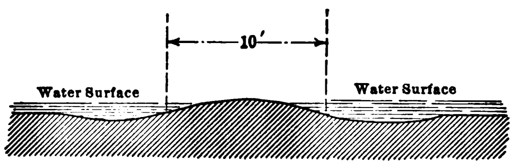

FIG. 71.—Cross-section of the low, wide field levee.

If the field is very large and the cuts are long the lateral should be extended down the slope dividing the cuts so that the water will not have to flow too far to reach the farther ends of the cuts.

SECURING WATER FOR IRRIGATION ALONG THE MISSISSIPPI.—Along the Mississippi River rice grows on alluvial land just over the levees. When the crop was first introduced into this section the planters cut the levees which protect the land along the river from overflow to get water to irrigate their rice or placed wooden gates or iron pipes in the levees to allow the water to flow from the river to their fields. After several crevasses and overflows resulted from this practice, a law was passed preventing the cutting of the levees. This made it necessary to syphon the water over them. As long as the river is low the water has to be pumped into a reservoir built beside the levee, and of sufficient height to cause the water to flow from it through the syphon to the field.

Small portable pumping plants are used to pump the water

from the river into the reservoirs. During the seasons when the river is high irrigation water is very cheap but when the river is low it is very expensive. On the Mississippi River above Baton Rouge, Louisiana, the fields are laid out and irrigated in much the same way as on the prairie lands. Below Baton Rouge the older method is still practised.

Some idea of the arrangement of field levees and ditches in different parts of the rice area may be obtained from the following outline:

The land along the Mississippi River slopes back to the swamp or low land. Parallel drain ditches are dug down this slope at distances varying from 200 to 600 feet apart. Levees are built along the sides of the ditches and cross levees at right angles to them for every drop of two- to five-tenths of a foot in the surface of the land. The cross levees thus range from 50 to 800 feet apart and form rectangular cuts of varying sizes. The water is allowed to flow from cut to cut across the field; and, when the field is to be drained the water is allowed to flow off through the drainage ditches.

Along the Atlantic Coast some of the land near the mouths of rivers influenced by tides, is level and lies between high and low tide. At high tide the fresh water of the river is backed up until it is higher than the land. Large, high levees are built around the field to hold the river water from the land. Inside field levees, generally straight, are built across the field to divide it into cuts approximately 40 acres in size. A large ditch or canal is dug in from the river and branches from the canal extend to each cut. Where the branch canals reach the levees surrounding the cuts a wooden box with a gate on each end to close it is placed under the levees. The box and gates together are called a "trunk."

The gates are arranged so that they can be set to work automatically and let the water on or off the field at the change of tide, whichever may be desired. A ditch about 4 feet wide and 4 feet deep runs from the trunk parallel to the inside levees and about 20 feet from them around the inside of each cut and back to the trunk. Other narrow ditches connect with the larger ditches from opposite sides, leaving room only for a team to pass between the ends. These inside systems

of ditches are made to allow the water to flow quickly to and from the fields while the tide is high or low.

Rice is cultivated on the Atlantic Coast only. In the other states the irrigation is not only expected to supply the moisture necessary for plant growth and to control the pests which attack young rice when the land is not flooded, but it is also expected to keep down the weeds and grasses. If there is not enough moisture in the soil to sprout the seed, water is applied just before or just after planting. It is not allowed to stand long on the newly planted rice, however, in order that the seed may not rot in the ground. The period of danger is from the time the rice starts to sprout until it is above the ground. If the field cannot be completely drained, sprout flooding can not be practised safely. The water should then be applied first and the rice planted as the land dries or planting should be delayed until rain falls.

If the corn beetles, wire-worms, white grubs, or birds are injuring the young rice, water is applied to drive the pests away even if the rice is just above the ground.

Application of Water.—Irrigation water is applied to the land when the rice is 4 inches above the surface. If the water is held deep when the rice is young, it will cause the plants to grow tall and slender at a rapid rate and not to thicken up or stool out to make many heads to each plant. If the weather is very hot, the water must be held not less than 1 inch and preferably 2 inches deep or it will become hot enough to scald the young rice. There is little danger of the water getting hot enough to injure the early planted rice but rice planted late in the season should be watched carefully.

After the rice has grown enough to shade the water there is no danger of scalding and the water may be allowed to get lower if desired. During cool weather the water should be held from 1 to 2 inches deep on the land in order that the sun may warm it quickly in the morning and the plants be given a chance to grow. After the rice has stooled properly in shallow water the water is held at an average of 4 inches or more on the cuts. The average depth of water on a cut is the depth midway between properly located contour levees. Tests to determine the depth of water which will cause the greatest yields have

shown that for old, grassy fields the yields increase with the average depth of water up to 6 inches and probably beyond. It is also true that the increase in yield is very slight for average depths greater than 4 inches. It is therefore not economical to flood deeper because it would require the use of a greater amount of water and the building of higher field levees. New land does not require as deep flooding as old land.

RICE WATER-WEEVIL OR RICE ROOT-MAGGOT.—The rice water-weevil resembles somewhat in size, shape and color, the weevil that eats stored grain and is most readily found when the rice has been flooded about 2 weeks and is 8 to 10 inches tall. It may be found on the leaves or stalks of the rice plants, or swimming in the water, but does little harm when eating on the leaves of the rice. When in the larva stage the weevils sometimes do great injury by eating the roots of the rice plants.

The rice maggot, as the rice larva is called by the farmers, is a small white worm about one-fourth to one-half of an inch long with corrugations or ridges running around it and both extremities somewhat blunt. Its head looks like little more than a reddish-brown speck. A rice maggot is found in wet soils near the roots of the rice plants but should not be mistaken for the larva of the greenhead fly which is sometimes found in wet or flooded rice fields, since the fly maggot does not injure the rice. The fly maggot is generally larger, of a darker color and with sharper extremities than the rice maggot.

If the rice maggots when discovered have just begun to eat the roots of the rice plants and there is a little rain to prevent the land drying, the water is drained from the cuts and the land is allowed to dry until the mud will not stick to the shoes but not so that the ground cracks. The water is then re-applied to the cuts. If the rice maggots have already done much injury and the weather is cloudy or rainy, or if irrigation water is too scarce to allow the water to be drained from the field, the cuts are flooded deep with fresh water. This seems to remain too cool for the rice maggots and also helps the rice to recover from its injuries.

After the field has been completely flooded the openings in the field levees are so placed that the water will flow in at one end of a cut and out at the other, also flowing down from

cut to cut across the field. This causes the water to circulate and prevents it from becoming hot and stagnant.

STRAIGHT-HEAD OR "BLIGHT."—Straight-head or "blight" sometimes causes great loss. This is an unfavorable growth of the rice plant occurring when too much of its strength goes to stalks and leaves and not enough to grain. It can be recognized by the tall stalks and dark green leaves during the growing period and by the empty or partly filled heads which stand straight up at harvest time.

This trouble seldom occurs on any but sandy loam soil which has not been planted to rice for a year or two. To remedy the defective growth the water should be drained from the field just before the rice begins to joint, permitting the soil to aerate until it is about to crack. The field should then be reflooded with fresh water. Rice planted on newly plowed prairie land is most apt to be injured by straight-head, although the danger is not so great after the first year. Even one plowing will so change the condition of the soil that there is little danger.

Water is handled on the rice fields along the Mississippi River in much the same way as further west. On account of weeds and grass on most of the older fields, the water is applied early and is held deep on the land throughout the whole season. Rice is not cultivated in this section and the small danger from straight-head on this soil makes drainage unnecessary. More water than that used on prairie land is generally required because the subsoils are not so compact. Weeds and grass are generally cut while water is on the ground.

HANDLING WATER ON ATLANTIC COAST RICE FIELDS.—Along the Atlantic Coast the rice fields are generally flooded as soon as the rice is planted. This flooding is called the "sprout flow." It protects the grains from the birds and causes the seed to germinate. The water is allowed to remain on the land 6 to 12 inches deep until little white sprouts one-third of an inch long have pushed through the hulls and caused the rice to be "pipped." This generally requires 3 to 6 days. The water is then drained off and is not re-applied until the rice is 1 to 2 inches tall with one point-like leaf.

The second flooding, called the "point or stretch flow" over the young rice causes it to grow quickly, getting a start on the

weeds and grass much of which the water is expected to kill. When the rice has grown to a height of about 6 inches the water is gradually lowered to an average depth of 4 inches and is held there for 13 to 30 days, according to the strength of the soil, the condition of the plants, and the temperature. Every week or 10 days the water is drawn off and fresh water is applied.

The "stretch flow" is followed by a period of "dry growth" which lasts from 40 to 50 days. If the weather is dry a short flooding is given during the "dry growth" period. During this period the rice is cultivated with horse plows 2 or 3 times and is hoed by hand once or twice. All weeds, grass, and red rice are uprooted and the ground is thoroughly stirred.

When the plants have begun to joint the "harvest flow" is turned on 4 to 5 inches deep and is allowed to remain until just before the rice is harvested.

Duty of Water, Rainfall, and Evaporation.—Measurements have been made of rainfall, evaporation, and the duty of water for irrigating rice on prairie lands of Louisiana, Texas, and Arkansas for 11 years, during which 21 measurements have been made. The averages of these measurements give 15.74 inches of pumped water and 17.16 inches of rainfall applied to the land and a loss due to evaporation from flooded rice fields of 15.33 inches. The total average depth of water applied was 32.90 inches. Subtracting the evaporation from this leaves 17.57 inches which was used by the plants, percolated into the ground and escaped through the outside field levees. Allowing time for break-down of pumping plant and for stoppage of pumping when irrigation water is not needed after rains, the duty of water for rice irrigation for prairie land runs from 7 1/2 to 8 gallons per minute per acre, depending upon the character of the land and the distance the water has to be carried in the canal. If the water is pumped at the field so there is no loss in a canal, less water will be required. For the black clay and loam soils along rivers, like that along the Mississippi River, 10 gallons of water per minute per acre should be provided while if the land has a loose subsoil and is located near a river or lake, 38 to 40 gallons will be needed.

In Texas, Arkansas, and all of Louisiana, except the strip along the Mississippi River below Baton Rouge, the water has

to be drained from the field in time for the land to become dry enough to support teams and binders at harvest time. This requires from 8 to 14 days according to the character of the land and the time required for the water to drain from the field. Generally the water is removed when most of the heads of the rice are in the dough stage, the end grains have begun to harden and the heads have turned yellow and filled enough so that most of them have turned down.

Along the lower part of the Mississippi River and the Atlantic Coast where the rice is still cut with sickles, the water is left longer on the field, and in some cases is drained off only the day before the rice is cut. In all sections the bundles of rice are shocked on the field and threshed by threshing machines driven by steam or gasoline engines.

Marketing.—Rice is generally sold to the rice mills through buyers who go over the country during threshing time to sample the rice. Frequently several buyers bid on the same rice. During recent years the rice buyers have organized a sales company called the Southern Rice Growers Association, the object of which is to give stability to the rice market and protect the growers by regulating the price, grading the rice, and selling it for the highest possible price, under the greatest competition from the buyers. The rice growers sign a contract agreeing not to sell their rice for less than the price fixed for that grade of rice by the association. In consideration of the assistance of the association in selling the rice and to provide a fund to be used to increase the consumption of rice, each member of the association pays into its treasury 7 cents a sack when his rice is sold.

Cost and Profits.—The cost of growing rice varies with the character of the soil, the price of labor, the cost of irrigation water, etc. For the prairie lands of Louisiana and Texas, when irrigation water is secured from canals, the approximate cost of growing rice is given on the following page.

This estimate is based on what a farmer could be hired to do the work for at regular prices. Where the farmer owns the equipment and does his own work or hires a hand by the month, the outlay will not be so great, since this estimate allows wages for the farmer and his teams and tools. According to the December

Crop Report of 1912, the average yield of rice per acre from 1909 to 1912, for Texas and Louisiana was 34 bushels, or 9.44 barrels, and the average price received during those years was $0.80 a bushel, or $2.80 a barrel. This makes a return of $27.20 per acre or $1.15 per acre less than the estimated complete cost of production. Both yield and price vary with different seasons.

Plowing	$1.50
Double disking	0.85
Double harrowing	0.60
Seed rice	3.00
Fertilizing	1.00
Planting	0.65
Rolling	0.30
Repairing field levees	0.35
Irrigation water	7.00
Handling water on field	0.40
Cutting rice	1.25
Binder twine	0.30
Shocking	0.50
Threshing	3.00
Marketing	0.90
Sacks (at 10 cents each)	1.00
Handling rice	0.50
Warehouse storage and insurance	0.75
Interest at 8 per cent. on land, houses, barn, etc., and loss of work animals	4.50
Total	$28.35

Cost of Production on the Arkansas Prairies.—The following itemized cost per acre of producing rice on the prairies of Arkansas where irrigation water is secured from wells, is based on what the cost would be if hired at market prices.

This estimate is based on the regular price of $6 per day for a four-mule team and machine or wagon and driver. The difference in the cost of production in Arkansas and that of the Gulf Coast is largely due to the greater cost of irrigation water. According to the Crop Reporter, December, 1912, the average yield of rice for Arkansas from 1909 to 1912, was 40.8 bushels, or 11 1/3 barrels per acre, and the average price received for the same years was $0.84 per bushel or $3.02 per barrel. This makes a return of $34.26 per acre and leaves $2.91 per acre more

than the cost of production. The causes of the larger yields and better prices for Arkansas rice are that a larger part of the land is new and the crops are given more careful attention than on the Gulf Coast. The yield and price of rice in Arkansas have gradually fallen and will be about the same as in other states in a few years, when much of the land becomes old.

Plowing	$1.50
Double disking	0.85
Double harrowing	0.60
Seed rice	3.00
Planting	0.60
Repairing levees	0.20
Irrigation water	10.00
Handling water on land	1.00
Cutting rice	1.50
Binder twine	0.40
Shocking	0.60
Threshing	4.00
Marketing	1.10
Sacks (at 10 cents each)	1.20
Hauling	0.80
Warehouse storage and insurance interest at 8 per cent. on land, houses, barn, etc	4.00
Total	$31.35

40. The Growing of Cotton under Irrigation.—About three-fourths of the cotton produced in the world is grown in the United States. Cotton is also grown in India, Egypt, Asiatic Russia (Turkestan), China, Brazil, Peru, Mexico, Turkey and Persia. Cotton crops are artificially watered in Egypt, India, Algeria, Persia, Turkestan, Mexico, Peru and Brazil but the practice in this country is of recent origin. In 1908 there were less than 5000 acres of irrigated cotton in the United States while in 1913 the acreage had increased to 80,000 acres. Cotton is produced in all of the southern boundary states from Georgia to California but only in California, Arizona, New Mexico and southwest Texas is it necessary to apply moisture artificially to produce a commercial crop.

In outlining the best practice to adopt in the culture and irrigation of cotton in this country the writer desires to acknowledge the assistance he has received from Mr. W.L. Rockwell, C.E.,

of San Antonio, Texas, who has gained through close observation and long experience an intimate knowledge of the behavior of this plant under irrigation.

PREPARATION OF THE SOIL.—Cotton is a semi-tropical plant and as such thrives best under a hot sun and in a warm soil. A high moisture content tends to reduce soil temperature, hence cotton makes the best growth in a moderately moist soil. Produced under proper conditions the cotton plant is very symmetrical. It sends a tap root deeply into the subsoil, and this is surrounded by a uniformly distributed system of rootlets. The plant is a strong feeder and requires a large area from which to draw its nourishment. It thrives best in a rather firm seed bed, which in irrigation is readily obtained. It is good practice to plow the ground as early and as deep as possible. Fall plowing is to be preferred to spring plowing. If at planting time the soil does not contain sufficient moisture to germinate the seed and start plant growth, water should be applied moistening the ground to a good depth. After irrigation, mulch the soil and plant immediately.

VARIETY AND SEED.—The cotton plant has two kinds of branches whose functions are distinctive. These are the vegetative, or those forming the framework of the plant, which are produced upright and bear no fruit, and the fruiting, which are thrown out laterally from the vegetative stems and carry the fruit. The variety grown should be one which is well supplied with fruit stems from the ground upward and each fruiting branch should retain from three to six bolls and rapidly develop these to maturity. The bolls should be large, of good length, uniformly cylindrical and the percentage of lint high. The fiber should be long, strong and of fine texture. A variety should be selected which is not inclined to "throw off" squares when water is applied, or when the temperature is high. When mature the bolls should open well, but in such a manner that the lint will not waste badly during storms.

To secure these characteristics and habits the seed should be selected from marked plants in the field, the selections being made during the growing and maturing periods. Cotton is a plant that readily hybridizes and deteriorates, so to maintain a uniformly high grade of produce, seed selection is of para-

mount importance. To produce upland and long staple varieties on adjoining farms, pure seed must be obtained every second or third year, and if other varieties of cotton are grown near fields of Egyptian, pure seed of the latter type must be imported each year.

The upland varieties as well as the long staple may be produced over the entire irrigated cotton area, though varietal habits and characteristics adapt certain types to certain localities. Egyptian, being a long season, late maturing plant can not be successfully grown in districts infested with the boll weevil.

Time of Planting.—The young cotton plant does not thrive during cool cloudy days, and the maturing of the crop is not hastened by too early planting. In southwest Texas it may be planted after March 1 until April 1; in west Texas, New Mexico, Arizona and southern California from March 15 to April 15. The short staple, short season cotton may be planted in districts not infested with the boll weevil as late as May 15.

Planting.—The customary method of planting in the Salt River Valley, Arizona, is to throw a ridge or back furrow every 4 feet and plant the seed with a hoe drill provided with a covering wheel in the center of each ridge. This method splits the original ridge into two smaller ones which effectively prevent the irrigating water breaking into the seed row and leaves an irrigating furrow on each side. The quantity of seed per acre varies from 25 to 30 pounds.

The depth of planting is regulated by the nature of the soil and percentage of moisture present. The seed should not be placed as deep in a clay as in a sandy loam. From 1 to 2 inches are allowable, but seldom is it advisable to plant over 1 1/2 inches in depth.

Spacing and Thinning.—A close study of the characteristics and habits of the cotton plant have recently brought about changes in the methods of culture, particularly in the width allowed between plants in the row, as well as the distance between rows. It has been found that when the plants are young, to allow them to crowd each other in the row holds in check the vegetative growth. This treatment also prevents the production of vegetative branches and induces the develop-

ment of fruiting branches. The proper distances between plants in the row can not be definitely stated since this is governed by variety, type of soil, and other conditions. Investigations thus far conducted indicate that a gradual thinning gives better results than if all extra plants are removed at one time. By thinning to a distance of 3 or 4 inches when the plants are 6 to 8 inches high, then by a second spacing to 10 or 12 inches, in sandy soils, 15 inches, when the plants are 10 to 12 inches tall, a more uniform stand is secured, and the crowding process is more uniformly maintained, thus securing a reduction in the vegetative branches. If these branches are allowed to develop wide spacing becomes necessary, else the rank foliage will shade the early fruit, prevent its maturing and only a light top crop will be secured. The width between rows varies from 36 inches to 54 inches according to soils and variety, lighter soils requiring the greater widths.

Methods of Irrigating.—Cotton, like other cultivated crops, is irrigated by means of head ditches and furrows. The distance between head ditches should not exceed 350 feet in sandy soils and 450 feet in clay loams. Most soils in warm climates bake after being thoroughly wet. On this account, the water should not be permitted to overflow the soil around young plants. In this regard the irrigation of cotton resembles that of potatoes.

Proper Time to Irrigate.—It is doubtful whether there is another annual crop produced that responds so favorably to proper methods of treatment. In the rich valley soils of the arid southwest there is a tendency to rank weed growth. With crops producing fruit like cotton this must be prevented or held in check. The soil at the time of planting should be moist for at least 4 feet in depth under which condition a considerable time may elapse before it will be necessary to apply more. The surface soil will gradually lose a part of its moisture and the roots will be induced to seek moister soil at lower depths. A large feeding area is thus made available and the roots are removed from the unfavorable climatic influences existing near the surface. By withholding moisture at the proper degree and following the method of close planting advocated the wood growth is held in check and the plant kept in a healthy normal

state. While in this condition it is best fitted to throw out fruiting branches and to begin setting fruit. Before a large number of flowers appear the crop should be given a 2 to 3-inch irrigation and during the period of fruit setting the soil should be maintained uniformly moist—not so moist as to produce a glossy, sappy appearance of the plant leaves, but one of healthy, balanced growth. The field is in fine condition when in looking over it flowers are more in evidence than leaves. The soil must not be allowed at this stage to become so dry as to check the growth, for if this occurs, when water is applied the plants will "throw off" their squares. Soil and other conditions are so varied that no rule can be given regarding the interval between irrigations. This must be determined by the farmer in studying the soil and the condition of the crop at various stages of growth. In close clay soils light applications at short intervals seem best, while in open soils heavier waterings at longer intervals will bring better results.

Cultivation.—Deep plowing before planting opens the soil to the air and the first irrigation firms the seed bed which is necessary for cotton. Cultivation should begin as soon as the plants appear and continue until they become too large to cultivate between the rows. The cultivation should be shallow and the sweep and harrow are the best tools to use. A very fine tooth adjustable harrow, in two sections and large enough to cultivate two spaces, should be used after an irrigation, since with this tool cultivation can be begun earlier than with a sweep. This implement also breaks up the surface so that it can be more readily pulverized by the sweep.

Cost of Production.—The cost of production and returns from a one-bale crop of upland cotton is herewith itemized. This estimate is based on labor at $1 per day without board, horses $0.75 per day with board, irrigation water $4 per acre per season.

Plowing ground	$2.50	
Seed	1.00	
Irrigation, water	4.00	
Irrigation, labor	1.00	
Thinning	1.00	
Cultivation	5.00	
Picking, 1500 pounds seed cotton @ 75 cents	11.25	
Ginning and baling	3.50	
Marketing	1.00	
Total	$30.25	
Overhead expenses		
Six per cent. int. on $150 land	9.00	
Taxes	1.00	
Interest and depreciation on tools	1.00	
	$11.00	
Total cost of production not allowing for superintendence		$41.25
Returns		
500 pounds lint cotton at 10 cents	$50.00	
1000 pounds seed at $25 per ton	12.50	
Total	62.50	
Net returns		$21.25

The cost of production of the long staples, such as Durango, Snowflake and Blackseed would be about $55, the difference being in the picking and ginning. It is worth about 5 cents more per pound than the Uplands and the returns would be about as follows:

500 pounds lint at 15 cents	$75.00
1000 pounds seed at $25 per ton	12.50
Less cost of production	55.00
Net returns	$32.50

Cost and returns of Egyptian cotton in the Salt River Valley, Arizona, no allowance being made for superintendence, is as follows:

(One bale crop)		
Plowing ground	$3.50	
Seed	1.00	
Irrigation, water	2.00	
Irrigation, labor	1.00	
Thinning	1.00	
Cultivation	7.50	
Picking, 1780 pounds seed cotton at $2	35.60	
Ginning and baling	12.00	
Marketing	1.00	
Total cost	$64.60	
Overhead expense		
Interest on $150 land	9.00	
Taxes	1.00	
Interest and depreciation on tools	1.00	
	11.00	
Total cost		$75.60
Returns		
500 pounds lint at 20 cents	$100.00	
1200 pounds seed at $25 per ton	15.00	
	$115.00	
Less cost of production	75.60	
Net returns	$39.40	

Mr. Rockwell believes that an average yield of one and one-half bales per acre is possible throughout the irrigated districts when proper care and skill are exercised by the grower. He considers the following features of first importance. (1) Early and deep plowing, (2) thorough irrigation before planting followed by a limited moisture supply after planting until the first flowers appear, (3) a sufficient and uniform moisture supply during the fruiting period, (4) a continuous shallow cultivation, (5) close planting in the row and subsequent crowding to hold in check the vegetative branching, (6) thinning gradually 10 to 15 inches apart by at least two operations.

41. The Growing of Sugar Cane under Irrigation.—Sugar cane is produced in all the Gulf States from Florida westward and for a distance of more than 200 miles inland from the Gulf.

Though grown in a number of southern states it is only in Texas and in the island possessions of the United States that it is irrigated. This subtropical plant requires a long growing season of at least 10 months to produce a profitable crop. In the Hawaiian Islands the first crop from seed requires 18 months to mature and the subsequent or stubble crops 22 months to reach maturity. The average crop thus obtained yields about 4 1/2 tons of sugar per acre. Coming inland from the Gulf of Mexico in Texas a distance of 75 miles or more the frostless period is not sufficient in length to produce a commercial crop of sugar but over a considerable area cane is grown for the manufacture of sirup.

Preparing the Soil.—Soils for sugar cane, according to Mr. Rockwell, should be rich in vegetable matter to furnish nourishment to the plant and to facilitate drainage. If the soil is deficient in humus, green crops, particularly leguminous crops should be plowed under. This can be readily done by a proper rotation. Soils adapted to the growth of sugar cane in this country are close grained and require deep plowing and subsoiling. The stirring of the soil to a depth of 20 inches is beneficial. Fields should be plowed as long as possible before planting and the surface thoroughly mulched with a disk.

Planting.—Sugar cane is reproduced for commercial purposes by planting the stocks. Great care should be exercised in their selection which should be made near the end of the growing period. Only a vigorous, early maturing stock should be chosen, having a good length of joint and plump, well-matured buds. The selected stock should be left standing as long as possible without injury from frost. Planting should begin whenever the seed crop has sufficiently matured for vigorous germination. The planting period extends from October into the winter season, but early planting is preferable since it lessens the risk of damage by frost to the seed, the drying out of the buds and other setbacks.

The rows spaced 6 feet apart are marked by a single shovel which is followed by a large middle breaker which opens the furrow 8 to 12 inches deep in one or two trips. The canes are cut in lengths of 4 to 5 feet or shorter if crooked and dropped in the furrow. If there are few infertile buds one stock in a place slightly lapped at the joints will furnish a good stand but if there is a

rather high percentage of poor, weak buds it may be necessary to drop two stocks alongside, breaking joints. Thus from 3 1/2 to 5 1/2 tons of seed per acre will be required. When the seed is covered to a depth of 3 inches irrigation water is run down the row and directly over the cane. The field is then harrowed to create a soil mulch which checks evaporation and any tendency to soil baking.

IRRIGATION.—Sugar cane, not unlike other cultivated grasses, grows most luxuriantly under humid conditions. The results of experience seem to show that the moisture content of the soil should not fall below 25 per cent. during the season. Dr. W. C. Stubbs, at one time Director of the Louisiana Experiment Station, states that 60 inches of well distributed rainfall is necessary for the largest yields. It is well to bear in mind, however, that cane produced under excessive moisture contains a low percentage of sugar, the heaviest sugar production being in districts of light rainfall where the moisture is largely supplied by irrigation. In the lower Rio Grande Valley of Texas during the season 1908–09, 42 acres produced 44.75 tons of stripped cane per acre. The soil was a sandy loam very well drained. The crop was planted during November and December. It received during the growing season 25 inches per acre in five irrigations and 8 acre-inches which were applied before planting made 33 inches in all. The total amount received by irrigation and rainfall amounted to 55.84 inches.

In retentive soils 12 to 13 irrigations of 4 inches each are usually applied to sugar cane. Two of these are generally given prior to February 1. In the 5-month period from February 1 to July 1 the interval between irrigations is 20 days and from July 1 to September 30 it is 30 days.

While a high moisture content in the soil increases the yield it also increases the moisture in the stock which adds to the cost of hauling and manufacture and undoubtedly decreases the percentage of sucrose. The more water in the cane the more the machinery required for reducing it and the greater the time consumed in evaporating. It is the action of the sun on the leaves that produces the sugar in the plant and when the time arrives for maturing and producing the sugar water should be withheld.

The furrow method of application is commonly used but there is a difference of opinion among growers as to the proper location

of the furrow. Some advocate running the water in a furrow along the cane row, others in two shallow furrows on either side of the row while still others make use of the flat central furrow. All growers agree in running the water along the row, the first two applications after seeding. The difference of opinion as to the location of the furrows arises perhaps from the action of the water in different types of soil. In heavy clay soils the water reaches the roots more readily if applied around the stocks which it follows into the ground. In open porous soils this advantage is lost and water is applied more readily alongside the row. The grower should watch the movement of moisture and learn the best method to apply in his individual case.

Head ditches having a capacity of 3 to 5 second-feet are constructed across the field at intervals of 300 to 600 feet. The grades of these ditches may vary from 0 to 2 inches per 100 feet. Ordinarily heads of from 2 to 3 second-feet are used in irrigating, each head being divided between 5 to 10 furrows.

CULTIVATION.—To prevent weed growth as well as to check evaporation and packing of the soil, cultivation should follow the application of the water and continue until the cane is too large for such treatment. The first tool used after irrigation should be one that will pulverize the surface without turning up moist soil from below. All cultivation should be shallow as cane is a grass and a shallow-rooted feeder. Until the crop thoroughly shades the ground cultivation should be continued.

When ready for harvesting the cane is stripped, cut, topped and placed in windrows on the ground and is then transported to the mill on wagons or treadways.

COST OF PRODUCTION.—Assuming that raw land in the lower Rio Grande Valley, Texas, is worth $115 per acre, the cost of clearing, leveling, ditching and the like would increase its value to $150 per acre. Assuming also that three crops are harvested before replanting, only one-third of the total cost of planting should be charged to each annual crop. On this basis the various items of cost per acre for a 45-ton yield has been estimated by Mr. Rockwell to be about as shown on page 242.

If one figures on a yield of 25 tons per acre which sells for $3 per ton, the cost would be reduced to about $50 and the net returns to about $37.50 per acre.

One-third cost of planting	$12.25
Irrigation water	6.00
Labor in irrigating	3.00
Cultivation with teams	5.50
Hoeing twice over	2.25
Cutting, stripping and topping	7.00
Hauling 1 mile	22.00
Overhead charges for interest, taxes, and depreciation	12.00
Total	$70.00
Gross returns, 45 tons at $3.50	$157.50
Net returns	$87.50

Owing to the heavy yields, long seasons, and other factors, large quantities of water are used in the irrigation of cane in the Hawaiian Islands. The following table gives a summary of the results obtained at the Hawaiian Experiment Station.

TABLE NO. 31

Experiment			Rainfall, inches	Irrigation water in acre-feet	Total water, acre-feet	Pounds of sugar produced per acre
Various crops	1897–1898		46.5	3.91	7.78	24,755
	1898–1899		26.9	6.33	8.58	29,059
	1899–1900	Rattoon	40.17	5.92	9.27	26,581
	1899–1900	Plant	40.96	7.21	10.6	30,682
	do	Plat 21	40.96	8.84	12.24	47,580
	do	Plat 22	40.96	8.00	11.4	45,268
	do	Plat 23	40.96	13.5	16.9	54,605
	do	Plat 24	40.96	8.08	11.5	42,505
	do	Plat 25	40.96	20.2	23.6	44,387
	do	Plat 26	40.96	8.33	11.75	31,890
	1903		70.51	5.08	10.95	24,164
Lahaina. One inch per week						
	1905		71.12	4.92	10.84	20,956
	1903		70.51	9.84	15.7	23,939
Two inches per week						
	1905		71.12	10.5	16.42	28,698
	1903		70.51	14.58	20.45	26,497
Three inches per week						
	1905		71.12	15.56	21.5	34,347
	1903		70.51	5.33	11.2	24,045
Two inches every two weeks						
	1905		71.12	5.00	10.92	20,698
	1903		70.51	5.58	11.45	19,452
Three inches every two weeks						
	1905		71.12	5.00	10.92	21,534

42. Irrigation of Onions.—Onions are grown chiefly for home consumption in all irrigated sections. Conditions in the Southwest and more particularly in the lower Rio Grande Valley, Texas, are so favorable for the growth of onions that their production on a commercial scale has become an important industry. According to W. L. Rockwell, the output from this valley in 1913 was 2,000,000 crates of 50 pounds each from 8000 acres.

FALL SEEDING AND SEED BED.—Some varieties are seeded in the spring in the direct and ordinary manner. The more common practice, however, is to sow the seed in seed beds in the fall and afterward transplant to the field. The white Bermuda is the most popular variety for fall seeding. The ground chosen for the seed bed should not have much slope and should be thoroughly leveled and the surface pulverized. Ordinarily the beds are laid out 10 to 12 feet wide and 30 to 50 feet long by constructing a head ditch along the ends of the rows and throwing up a back furrow at right angles to the head ditch. The seed is drilled in by hand late in September or early in October on a flat surface not to exceed 1/4 inch in depth in rows 12 inches apart, about 25 pounds of seed per acre being used. An acre of seed bed will furnish plants for 8 acres in the field. The soil is kept moist by frequent light flooding or sprinkling, the overhead spray method being well adapted to seed bed irrigation. As soon as the plants appear cultivation with hand tools begins. By December 1 to 15 the plants should be the size of lead pencils when they are ready to transplant.

PREPARATION OF THE FIELD.—The field should be well plowed and the surface thoroughly leveled and pulverized. Ordinarily the furrow or border method of irrigation is practised. In either case the head ditches are spaced from 35 to 200 feet apart and are given a capacity of 1 to 3 second-feet. The beds are made from 10 to 14 feet wide by turning a back furrow with a turning plow or disk.

TRANSPLANTING.—Care should be exercised in securing good seed and thrifty, vigorous transplants are of equal importance. The latter should be graded to secure a more uniform maturing and a better crop. They are pulled from a moist seed bed, the roots clipped to 1.4 inches and the tops cut back, leaving a plant about 5 inches long. They are distributed along the row set 3 or 4

inches apart and 2 1/2 inches deep, the soil being placed closely about them.

IRRIGATION.—Immediately following transplanting the field is irrigated by flooding between borders or along the rows. One to three irrigations may be necessary prior to February depending on the season. During the growing period water is applied every 8 to 12 days at a rate of 1 1/2 to 4 inches per application. Eight to ten irrigations are given in all, totaling 12 to 30 inches. Under economical methods of distribution and use, 18 inches will mature a crop. Heads of from 1 to 3 second-feet are used, a second-foot being divided between two beds or else between 20 to 35 rows.

HARVESTING.—Upon the first sign of the tops falling irrigation should cease. When the plants are mature, indicated by the fallen tops, they are plowed out with a single shovel plow, placed in windrows and allowed to dry. The roots and tops are then clipped and the onions placed in crates and hauled to the sorting shed. After grading they are packed in 50-pound crates and stored or placed upon the car.

COST OF PRODUCTION.—Mr. Rockwell estimates the cost of producing a crop of 300 crates per acre at $139, this total being made up of the following items.

Preparation of seed bed	$1.00
Irrigation of seed bed	0.50
Seed	4.00
Preparation of field	7.50
Transplanting	12.00
Irrigation water	10.00
Labor in irrigating	7.00
Cultivation	6.00
Plowing and windrows	3.00
Topping and clipping	8.00
Grading and crating	4.50
300 crates at 18 cents	54.00
Hauling to car 3 miles	4.50
Interest on land	12.00
Taxes	2.00
Depreciation on tools	3.00
Total	$139.00

The yields vary all the way from 100 to 600 crates per acre and the price from 50 cents to $1.50 per crate.

43. Irrigation of Grapes. THE NEED OF IRRIGATION.—The growing of grapes under irrigation is perhaps less usual in the western United States than their growth without irrigation. This is mainly due to the fact that in general less moisture is required for grapes than for most other fruits. A further probable reason is that the advantage to be gained by irrigating grapes on the less moist soils is not yet fully appreciated; and besides, considerable areas of grapes are grown on hillsides where water for irrigation is not available and where its distribution would be very difficult even if it were at hand.

VARIETIES USUALLY GROWN.—While grapes are found throughout the United States, their commercial production in the western United States is mainly limited to the Pacific States and they are most largely found in California. For the perfection of the grape rather higher temperatures are required during ripening periods than obtain in the mountain areas of the interior. While the commercial grapes of the eastern and central states are varieties of native American species, the commercial grapes of California and the other Pacific slope states are varieties of the European species Vinifera, although several American species, as Riparia, and Rupestris, are used as grafting stock for the Vinifera and other European species grown commercially in the West. Wickson lists the following as the most popular varieties among California fruit growers: Muscat, Tokay, Cornichon, Thompson, Emperor, Malaga, Rose of Peru, Zinfandel, Black Morocco, Sweet Water, Verdal, Carignane, Black Prince, Alicante, and Sultana.

WHEN AND HOW TO IRRIGATE.—There is no well-established practice in either the time or the manner of irrigating grapes. In the Fresno section of California, which is the raisin-grape center of the United States, where the ground water is in most cases relatively high, it is customary to irrigate only during the first 2 years of growth, the vines receiving ample moisture after that from below. In such cases the usual practice is to apply water twice during the season, with a total seasonal application of about 1 acre-foot. Some growers, however, prefer to apply the same amount in four irrigations instead of two. On the higher ground about Fresno vineyardists usually apply water on old vineyards at least once each season. In the vineyard sections of Sacra-

mento and San Joaquin Counties, California, some growers irrigate more frequently, watering every 7 to 14 days, with as many as 14 or 15 in a season not being uncommon. Many of the vineyardists in these counties, however, do not irrigate at all. In the Napa and Sonoma county grape sections of California, where the annual rainfall averages from 25 to over 40 inches, vineyards are not irrigated nor are southern California vineyards usually irrigated, except in the desert sections, as about Coachella where they receive three or four waterings annually. While, as indicated, practice varies widely, the general principle to bear in mind is that, whether they receive it from rainfall or by irrigation, vineyards should have ample moisture prior to and at the time of budding in the spring, with a diminishing amount as the season advances. The quantity to apply is dependent entirely on the retentiveness of the soil and on the amount lost by evaporation, from 15 to 20 acre-inches per year probably being the minimum quantity it is desirable to apply in addition to rainfall. Care must be taken not to irrigate late enough in the season to stimulate growth of the vines beyond ripening of the fruit. Bioletti holds that with deep soils very retentive of moisture best results are obtained by withholding all irrigation after April, the moisture then in the ground to be conserved by cultivation. In shallower or less retentive soils he holds that an irrigation just after the fruit is set and another a little before it reaches full size are advisable. In any case, too frequent irrigations should be avoided with grapes as with other deciduous fruits.

The usual method of irrigating vineyards is by means of furrows. About Fresno, California, two furrows are run in each "land" 12 to 24 inches from the vines, small checks being placed across the furrows every four or five rows to hold the water. In the best practice the water is confined to the furrows, the more crude practice practically resulting in the basin method sometimes used in orchards. Frank Adams states that "One of the best systems of vineyard irrigation observed in California was seen at Elk Grove, Sacramento County. There furrows about 12 inches deep are plowed in every other 'land' by means of a five-horse home-made sulky lister plow with enlarged mouldboards, the furrows later being enlarged to a bottom width of about 6 inches and 'packed' with a home-made 'logger' constructed like an ordinary crowder

and shod with steel plates. By this method of furrowing shallow wetting and consequently shallow rooting of the vines are prevented."

44. Irrigation of Small Fruit.—The berry patch is almost as common and almost as indispensable on irrigated farms as the family garden. The area devoted to the commercial growing of small fruit under irrigation is, however, comparatively small and is of necessity limited to sections having easy access to large markets.

The crops discussed in this article include strawberries, raspberries, blackberries, loganberries and dewberries. The methods of cultivation and irrigation of these crops vary only slightly in the different irrigated sections.

STRAWBERRIES.—Strawberries are the most important berry crop grown commercially in the West. They can be grown on a variety of soils but thrive best on a sandy loam. The lighter soils produce earlier berries but the heavier soils often give larger yields and for a longer period. One of the chief essentials is that the soil be well drained and for this reason a porous subsoil is desirable.

Ground which is intended to be planted to strawberries should be plowed 8 to 10 inches deep, thoroughly pulverized and brought to a uniform grade entirely free, if possible, from high spots or depressions. The soil should contain a good supply of moisture at the time the plants are set out.

In setting out plants a good way is to make a hole with a trowel, insert the plant and press the earth firmly around it with the hands. The roots should be cut to a length of about 3 inches. It is a good plan to carry the plants in a vessel containing water until they are ready to set in the ground. There are two general methods of planting, known as the hill system and the matted row system. The former system consists of growing the plants in rows and keeping the runners cut off. In the matted row system the rows are marked off 3 to 4 feet apart and the plants set 1 to 2 feet apart in the row and the runners allowed to fill the intervening space. There are various modifications of these methods. In Oregon if plants are to be cultivated both ways they are usually set $2\ 1/2 \times 2\ 1/2$ feet apart or 3×3 feet apart. If not intended to be cultivated both ways they are set $4\ 1/2 \times 3$

feet apart. In southern California the rows are usually 2 × 2 1/2 feet apart. Sometimes they are set on ridges in double rows 6 to 10 inches apart, the ridges being 30 to 32 inches apart between centers. In Colorado if the hill system is used the rows are 2 1/2 to 3 feet apart and plants 12 inches in the rows. If the matted row system is employed the plants are set 18 to 24 inches apart and the rows 3 1/2 to 4 feet apart. By the hill system larger berries are produced but the yield is larger and the fruiting period longer when the matted row system is followed. Size, beauty and good shipping qualities, rather than flavor, are the things aimed at by the commercial grower. Plants may be set out either in the spring or fall but if the winters are at all severe spring planting is preferable.

It is of vital importance that strawberries have an ample supply of moisture at all times, especially during the fruiting stage. Few plants are quicker to feel the effect of a deficiency of moisture than strawberries. In southern California water is applied every 6 to 10 days throughout the growing season. Local soil and climatic conditions must govern the amount and frequency of irrigation but the condition of the soil and plants should be carefully observed and water should be applied before the plants begin to suffer. After the vines cease to bear one or two irrigations usually suffice.

In Colorado the best practice consists in making shallow furrows close to each row of plants as soon as they are set out and water is applied immediately even if the ground is moist. This settles the earth around the plants, is an insurance against possible dryness and gives the plants a vigorous start. In order to properly regulate the amount of water in each furrow it is best to take the water from the supply ditch through metal tubes or lath boxes rather than to make cuts in the ditch bank.

Some growers prefer to irrigate in every alternate row while the dry rows are being picked. This makes it possible for irrigation and picking to proceed at the same time. It is important that the berries be picked frequently, every day if possible, as it is detrimental to the vines to allow fruit to decay on them.

The profitable life of strawberry vines is 2 to 5 years. Most growers claim they are not profitable after the third year. Strawberries should be cultivated or hoed frequently throughout

the growing season in order to keep down the weeds and aerate the soil. One large grower in Pajaro Valley, Cal., cultivates ten to twelve times per season and hoes six times.

Among the popular varieties of strawberries grown in the West may be mentioned the Brandywine and the Klondike.

IRRIGATION OF STRAWBERRIES IN SOUTHWESTERN TEXAS.—The cost of growing, harvesting and the profits of an acre of strawberries are given in the following table compiled by C. G. Haskell, Austin, Texas.

Cost		
Plowing	$2.00	
Ridging	1.50	
Fertilizing	4.00	
Plants	8.00	
Planting	4.00	
Cultivating and hoeing	15.00	
Mulching	20.00	
Irrigating	20.00	
Interest on investment	16.00	
		$90.50
Harvesting 102 crates @ 60 cents		61.20
Crates @ 15 cents		15.30
Selling @ 15 cents		15.30
Total cost		$182.30
102 crates @ $2 per crate		$204.00
Profit per acre		$21.70

Within recent years truck growers in southwest Texas have learned the value of supplemental irrigation for their crops, especially strawberries. Conditions are favorable for pumping water, the lift being low, from 30 to 40 feet, the supply of water abundant and fuel oil cheap.

Water is pumped to the highest side of the field through 2- or 3-inch iron pipes. It is taken from the discharge pipe into light galvanized pipes, movable wooden flumes or old fire hose from which it is distributed to the rows. The rows vary in length from 150 to 1000 feet, about 400 feet being considered the best length. The water is usually applied in every alternate furrow except on the steep slopes where it is applied in every row. Only enough water is allowed to flow in the furrows to reach the

lower end of the row, care being taken to prevent it from touching the plants or wetting the tops of the ridges. The best practice is to irrigate every 10 days or 2 weeks during dry weather, the aim being, of course, to apply water before the plants begin to suffer for lack of moisture.

The good effects of irrigation upon the yield and quality of strawberries in this section is very marked. Where irrigated and non-irrigated strawberries have been grown side by side it has been found that in dry years the yield from the part irrigated was about double that from the unirrigated strawberries.

Raspberries.—Raspberries are of two general kinds, red raspberries and black raspberries or black caps. Like strawberries and other small fruit they require a well-drained soil. In the Pacific Coast States they are planted either in hills 6 to 8 feet apart each way or in continuous rows 5 to 8 feet apart and 3 to 5 feet apart in the rows. In the Rocky Mountain States if winter protection is necessary the rows are spaced about 7 feet apart and plants 2 to 3 feet apart in the rows. When winter protection is not necessary the rows are 5 to 6 feet apart and the plants 3 to 5 feet apart in the rows.

In sections where the winter temperature is likely to remain at zero or lower for any length of time it is necessary to cover the plants to protect them from winterkilling. This is accomplished by removing the earth from one side of the row and bending the canes over to the ground, then partially covering with coarse manure or earth.

In California the planting season extends from November to February while in the mountain states plants may be set out either in the spring or fall, spring planting being preferred if the winters are severe.

Raspberries require a moderate amount of water. The aim should be to keep the surface soil in a fairly moist condition throughout the growing season. Water is applied in shallow furrows as near to the rows as possible without danger of injury to the plants in cultivating. Irrigations should occur at intervals of 10 days to 3 weeks. In some soils even more frequent irrigation may be necessary but frequent cultivation will reduce the number of irrigations required. Each irrigation should be followed by a shallow cultivation. Deep cultivation during the

growing season is never advisable for bush berries of any kind, since it disturbs the delicate feed roots near the surface. Some growers in southern California have an extra ridge between the rows which provides a dry path for the pickers to walk on.

It is a good practice to prune all old canes just after the fruiting season and later cut the main canes from 3 1/2 to 4 feet in length and remove all small, inferior growth. Where there is danger of winterkilling it is best not to remove the old canes until spring.

A common method of trellising the vines is to sink a line of posts 4 or 5 feet high in the row to which an 18-inch cross arm is nailed 3 feet from the ground. To the ends of these arms heavy wires are stapled thus forming lateral supports for the canes. Many growers, however, do not consider it necessary to provide supports of this kind.

The Cuthbert is one of the most common of red raspberries and the Gregg is prominent among the black caps.

Blackberries.—What has been said regarding raspberries applies equally as well to blackberries, since the habits and requirements of these berries are very similar. The blackberry is hardier than most other bush berries and will not suffer as quickly from drought but an ample supply of moisture is nevertheless necessary for an abundant yield of large, luscious berries.

Dewberries.—These berries, distinguished from blackberries chiefly by their low, trailing habit, if anything are probably more dependent on water than are blackberries. They are planted shallower than blackberries and are probably best irrigated by means of furrows midway between the rows rather than close to them as is the case with blackberries. Having the vines high enough to keep them well out of the water when irrigating has been found to be a good practice. The fruiting season of the dewberry is earlier than that of the blackberry and for that reason it is more dependent on early waterings.

Loganberry.—This berry is a California hybrid of the wild blackberry and red raspberry. Its treatment should be similar to that required for the raspberry except that it is less adapted to successful growing without irrigation and is usually spaced wider apart in the rows.

Currants and Gooseberries.—These are more limited in their area of successful growth than are any of the bush fruits previously

mentioned, due chiefly to the fruit being unable to stand the hotter sections. In California they are usually grown commercially within the cooling influences of the coast. They should be irrigated by furrows and deeper cultivation is possible with them after irrigation than other berries. Ample moisture should always be kept in the soil during the growing and fruiting seasons.

45. Supplemental Irrigation on the Atlantic Coast.—Irrigation development along the Atlantic seaboard differs in many essential features from that of the arid region. The most striking of these differences pertain to the size of tract irrigated and the form of organization adopted. In the West it is customary to include a large area in one project and to organize farmers under it. In the East a small area comprising the most fertile parts of a single farm is irrigated by the owner. This may be accomplished by one of three systems of irrigation, viz., surface, subsurface and overhead spray, or by combinations of the first and third as described in Art. 24. The plant for surface irrigation usually consists of a gasoline engine, centrifugal pump and underground mains of vitrified clay or concrete. The equipments for the other systems named have been described in Art. 23 and 24. Potatoes, tobacco, corn, orchards, bush berries and other row crops can be successfully irrigated by the surface method providing measures are taken to adapt it to local conditions. Owing to the shallow soil, the surface can seldom be reduced to an even grade by removing earth from the high places and filling up the low places. Owing also to the undulating character of the surface the distribution pipes and furrows can not be laid out with that regularity common to the West. As a rule the pipes follow the ridges and the furrows are short. At intervals of about 40 feet hydrants are placed on the pipes and to these are attached portable surface pipes from which the water is distributed over the surface or in furrows.

Again it is not possible to figure out in advance the amount of water that will be needed for any particular crop. If the season is wet little water may be required. On the other hand, if the season is dry the duty of water may approach that of an arid country. There is likewise much uncertainty in applying water. A heavy irrigation may be followed by a heavy rainstorm.

Taking into consideration shallow-rooted crops in shallow soils

and the uncertainty of the rainfall it is better to apply light irrigations of not more than 2 acre-inches per acre whenever the crops are in need of water. It is also customary in planning an irrigation plant to allow a seasonal duty of 1 acre-foot per acre. This is reasonably certain to suffice for all crops with the possible exception of alfalfa.

The investigations conducted by Milo B. Williams for the Office of Experiment Stations have demonstrated that the economic advantages of irrigation in the Atlantic Coast States should not be measured wholly by increased yields or a better quality of products. Under intensive farming where large sums are expended for fertilizers waiting on rain to sow the seed or to cultivate the soil may prove very costly. The farmer who can moisten the soil by artificial means, and plant a crop gains the advantage of having highly fertilized soil utilized without delay from dry weather. The time thus saved often makes possible the growing of an additional crop on the same ground in one season at the same cost for fertilizer and at a reduced cost for labor. By properly controlling soil moisture, weeding and cutivating can be done in the best manner at the least expense and a crop of maximum yield can be produced in the shortest time and with the least risk from disease, frost, or other unfavorable conditions.

One of the greatest advantages of supplemental irrigation lies in the fact that irrigated crops can usually be marketed ahead of non-irrigated crops. Crops can not well be planted during droughts and if planted their growth is checked. By applying water when needed at critical stages of growth the irrigator loses no time and produces a heavy crop of good quality which he markets before the bulk of like crops in his district are mature.

46. Dry-farming in its Relation to Supplemental Irrigation.— Dry-farming is the growing of unirrigated crops by special methods of tillage and cropping in regions where the average seasonal rainfall is not sufficient for profitable farming if ordinary methods are employed. In such regions it is necessary, in the case of row crops to maintain a surface mulch by frequent cultivation which will prevent to a large degree the escape of moisture by surface evaporation, and in the case of small grain, hay, or forage crops it is found that thin seeding is advisable since a few strong plants will produce a larger yield of a marketable product than a

thick stand which is starved for lack of moisture. Another common practice in dry-farming regions is known as sunmer fallowing, which consists of allowing the land to lie idle every other year and by keeping it free from weeds and maintaining a surface mulch, store water in the soil for the crop planted the following year. The employment of special methods to pack or firm the soil after plowing, the growing of drought-resistant crops, and a rotation of crops which includes a leguminous crop to maintain the fertility of the soil and increase its water-holding capacity, are other important aids to successful dry-farming.

The extent of land which is adapted to dry-farming is not very definitely known. Between the line of 20-inch rainfall and the margin of the arable lands along the main range of the Rocky Mountains, there is an area of over 250,000,000 acres, the greater part of which will have to be farmed, if at all, by dry-farming methods. In addition to this Great Plains area, there are large areas of dry-farming lands on the Pacific slope of the Rockies. California, for example, contains over 10,000,000 acres of arable land which can not be irrigated on account of the lack of available water. If one assumes that the water supply of the seventeen western states will be wholly utilized when 50,000,000 acres are irrigated, there will remain over 300,000,000 acres of arable land to be dry-farmed or else pastured.

According to the last census, sufficient water is annually diverted to cover the entire irrigated area of this country to a depth of over 57 inches. To furnish and apply water so wastefully to even a small part of the dry-farming land is impracticable. It is, however, practicable in the majority of cases to secure from 1 to 1 1/2 acre-feet of water per acre for small tracts that are intensely farmed or else from 4 to 8 acre-inches per acre for larger tracts. This is what is meant by supplemental irrigation for the dry-farms. Water supplies for this purpose can be obtained from streams and wells. As a rule the summer flow of the streams is diverted and used but immense quantities of water go to waste outside of the regular crop-growing season. A part of the water which is now wasted might be stored in reservoirs and used on dry-farmed lands. Another part might be diverted in the late fall, winter, or early spring and stored in the soil. Then, too, underlying a part of the

vast areas of dry-farming lands are to be found water-bearing strata from which water may be pumped.

On account of the larger returns per acre from a small tract which is both irrigated and intensively farmed, a farmer is justified in paying much more than the average price for water. A small storage reservoir when safely built does not depreciate in value to any extent and costs little to maintain. The main item of expense is the interest on the first cost, which varies from a few dollars per acre-foot of water stored to over $100.

The factory cost of a serviceable 14-foot windmill varies from $150 to $200.[1] This includes the steel tower 40 feet high and the pump. The freight charges, assembling and erecting would add $45 to the factory price. Much of the work of digging a well and of building a small reservoir can be done by the farmer so that the total outlay of cash for a plant of this kind need not exceed $450. The maintenance and repair bill together with the depreciation are usually high, especially when the windmill is not properly cared for.

In recent years oil-burning engines have been much improved in both efficiency and serviceability. Portable engines as now manufactured form a valuable part of dry-farm equipment. The farmer who desires to pump water for a small part of a large dry-farm can now make his selection from a large number of types of internal combustion engines. Apart from the gasoline engine proper, there are on the market engines adapted to the burning of distillate, crude oil and semi-crude oil. Assuming that the land is carefully prepared for irrigation and the water economically applied, a duty of 15 inches in addition to the rainfall will suffice for average crops in dry-farming districts. The cost of raising this quantity of water for 1 acre from a well 100 feet deep by means of an oil-burning engine and a good pump will vary between rather wide limits depending largely on the price of suitable oils. If one installs a gasoline engine and burns gasoline at 20 cents a gallon, the cost per acre including all charges will not be far from $11 for the season. With distillate at 8 cents a gallon and a distillate-burning engine this cost may be reduced nearly one-half. Furthermore, if crude oil or semi-crude oil can be obtained at 4 cents a gallon and used in a crude-oil or Diesel type of

[1] The use of small water supplies for irrigation. Yearbook, 1908.

engine the cost may be still further reduced to about $3.50 per acre. In using an electric motor and current at 2 1/2 cents per K. W. the cost for the season will be approximately $6 per acre.

In Bul. 70 of the Arizona Experiment Station it is stated:

"When yields of 35 to 50 bushels of milo maize per acre can be obtained by pumping from 4 to 6 acre-inches of water upon the land during the winter months when other work is slack, it is useless to resort to the great amount of labor required by summer-fallowing to produce the very meager yields obtained by that method of farming. The increased yields by supplemental irrigation are not so much the result of more water in the soil as of a small amount of water applied at a critical time. Thus the application of 2 to 3 inches of water at a critical time makes the difference between absolute failure and satisfactory success."

At the Cheyenne Experiment Farm in charge of John H. Gordon oats on which 9.55 inches of water were applied in 1913 yielded 63 bushels against 31 bushels on dry-farmed land. Wheat which received 10.25 inches yielded 35 bushels against 13 bushels on non-irrigated land. Alfalfa which received only 13.20 inches of irrigation water yielded 8500 pounds, whereas unirrigated alfalfa produced only 1800 pounds. These are striking examples of the beneficial effects of a small amount of water applied at critical periods of the crop growth.

In J. A. Widtsoe's "Dry-farming" it is stated that Forbes of Arizona found that a 12-foot windmill pumping water from a well 90 feet deep into a 5000-gallon storage reservoir supplied water for household use and for the irrigation of 61 olive trees, 2 cottonwoods, 8 pepper trees, 1 date palm, 19 pomegranates, 4 grape vines, 1 fig tree, 9 eucalyptus trees, 1 ash and 13 miscellaneous, making a total of 87 useful trees and 32 vines and bushes.

Widtsoe also states:

"The dry-farmer should carefully avoid the temptation to decry irrigation practices. Irrigation and dry-farming of necessity must go hand in hand in the development of the great arid regions of the world. Neither can well stand alone in the building of great commonwealths on the deserts of the earth."

It is evident from the foregoing that a wise use of limited water supplies is certain to become an important factor in the settle-

ment of semi-arid lands and the ultimate success of dry-farming. Homes cannot be established without water. A domestic supply for man and beast is indispensable. Now it is feasible in the majority of cases to increase the supply for household and stock purposes sufficiently to irrigate a few acres around the home. A small amount of water carefully used soon brings about a wonderful change. A green lawn covers the drifting sand, shade trees intercept the burning rays of a western sun, cacti and sage give place to flowers and fruit and vegetables fresh from the garden render canned goods from the factory no longer a necessity. In a larger sense the use of limited water supplies on the dry farm insures a much larger yield by applying a small quantity of water to the crop at a time when it is most needed. This larger yield means closer settlement, better social conditions, and everything that goes to make up our best rural communities.

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